Mathematical Elements

OF

NATURAL PHILOSOPHY,

CONFIRM'D BY

EXPERIMENTS:

Or, an INTRODUCTION to

Sir *ISAAC NEWTON*'s Philoſophy.

32 c 11

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VOL. II.

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BRITISH MUSEUM

Mathematical Elements
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EXPERIMENTS.

BOOK IV.

PART I. Of Air, and other elaſtic Fluids.

CHAP. I.

That Air has the Properties of Fluids.

2074. THE Fluids, that we conſider'd in the third Book, have contiguous Parts, which cohere but a little, between which nevertheleſs ſome ſmall Coheſion is obſerv'd. Theſe Fluids are not brought into a leſs Space by Compreſſion; at leaſt, if there be a Diminution of Space, it is ſo ſmall, that it could not be diſcover'd hitherto, in any great Compreſſion whatever; for that which ſeems to ſhew ſuch a Diminution in ſome Experiments, may be eaſily attributed to another Cauſe. Thoſe Fluids have this Property alſo, they are contain'd in Veſſels open at top.

2075. But there are other Fluids, which are to be reſtrain'd on all Sides leſt they ſhou'd flow away; and occupy a greater, or leſs Space, according as they are compreſs'd by a greater, or leſs Force: Theſe are call'd elaſtic Fluids; and among theſe the Air, with which the Earth is ſurrounded, is the chief. I ſhall ſpeak of this now, and demonſtrate firſt of all, that this is to be rank'd amongſt Fluids.

We have often ſpoken of the Air already, and as we live in, and are always encompaſſed by it, we muſt have Regard to it's Effects in ſeveral Experiments, as we have ſaid; but now we ſhall conſider it's Properties ſingly.

2076. We call that Fluid, which covers the Surface of the Earth, and ſurrounds the Earth on every Side, the Air.

2077. But it is manifeſt that the Earth is ſurrounded by a Fluid; for we obſerv'd that it is cover'd by a Body, that gravitates, whoſe Parts yield to any Impreſſion, and are eaſily mov'd among themſelves, which preſſes according to it's Height, and whoſe Preſſure is equal every Way.

2078. Many call any elaſtic Fluid whatever Air; others affirm that in the Air, which covers the Earth, there are many Things mixt, which don't belong to the Air; and that therefore we muſt attribute no Properties to it, except thoſe, which belong to it, when all theſe Things ſhou'd be ſeparated from it.

2079. But we have clearly explain'd what we underſtand by Air *;
* 2076. namely this mixt Fluid, by which the Earth is ſurrounded. And we look upon thoſe Parts only as not belonging to it, which are thicker, and can't be rank'd among the Parts of the Fluid, but float in it.

Definition 1.

2080. *All the Air which the Earth is encompaſs'd with, conſider'd together, is call'd the Atmoſphere of the Earth, or ſimply, the Atmoſphere.*

Definition 2.

2081. *The Height of the Air above the Surface of the Earth, is call'd the Height of the Atmoſphere.*

2082. That there is a Body every where on the Surface of the Earth, though it's Parts generally eſcape the Sight, is diſcover'd by Expe-
* 24. riment *.

2083. That *it yields to any Impreſſion, and has it's Parts eaſily mov'd*, is not doubted by any one.

2084. That *it is heavy*, is prov'd by its preſſing upon the Surface of other Fluids, and ſuſtaining them in Tubes.

Experiment 1.

2085. Take a Glaſs Tube A B, about three foot long, of about $\frac{1}{4}$ Inch
Pl.63.F.1. Bore; if you ſtop up the End A, and let the Tube be fill'd with Mercury, and let the other End be immerſed in a Veſſel, that has Mercury

Mercury in it, the Mercury will be ſuſtain'd at the Height of about 29 Inches.

This is occaſioned by the Preſſure of the Air upon the Surface of the Mercury in the Veſſel; which cannot be preſſed equally in every Part, unleſs in the Tube, where no Air is, there be a Column of Mercury, which preſſes equally with the outward Air *. This is called the *Torricellian* Tube, from *Torricelli*, who was the firſt that made this Experiment. 2086. * 1416.

Experiment 2.

That this Preſſure may not be chang'd when the Tube is inclin'd, it is requir'd that the Mercury ſhould keep the ſame perpendicular Height *: If therefore there be two Veſſels containing Mercury, in which Tubes in the Manner abovemention'd are immers'd, of which ED is inclined to the Horizon, the Mercury is ſuſtain'd at the Heights *h f* and *i g*, ſo that *f* and *g* are in the ſame horizontal Lines; ſuppoſing the Surface of the Mercury in the Veſſels to lye in the ſame Plane. 2087. Pl.63.F.1. * 1423.

Experiment 3.

The ſame Preſſure of Air ſuſtains the Water of the Glaſs V, which is immerg'd in Water and filled with it, and then is pull'd out all but the Orifice, which ſtill remains immers'd. 2088. Pl.63.F.2.

Water wou'd be ſuſtain'd in the ſame Manner tho' the Height of the Glaſs ſhould be 32 Foot; for Quickſilver is almoſt 14 times heavier than Water *, and a Pillar of Water a little more then 32 Foot high preſſes equally with a Column of Mercury 29 Inches high, which Preſſure is equal to the Preſſure of the Atmoſphere. 2089. * 1563.

Experiment 4.

In the Glaſs A, inverted, a Fluid, as Water, would be ſuſtain'd by the Preſſure of the Air, unleſs, by the Water's deſcending, the Air ſhould aſcend along it into the Glaſs; for this Reaſon if the Glaſs, before it be inverted, be cover'd with Paper, the Water is kept in, and the Paper is applied faſt to the Water, by means of the Preſſure of the Air. 2090. Pl.63.F.3.

That *the Preſſure of the Air depends upon it's Height*, may be eaſily deduced from what has been ſaid; but it is immediately prov'd by carrying the *Torricellian* Tube mention'd to a higher Place; for, when you carry this Machine up a Hill, for 100 Foot that you riſe perpendicularly, the Mercury deſcends about an eighth of an Inch. 2091.

2092. That *Air preſſes equally every Way*, appears from this, that the Preſſure is ſuſtain'd by ſoft Bodies without any Change of Figure, and brittle Bodies without their breaking, tho' this Preſſure be equal to the Preſſure of a Pillar of Mercury 29 Inches high, or a
* 2089. Height of Water of 32 Foot *; any Body may ſee that nothing can preſerve theſe Bodies unchang'd, but the equal Preſſure on all
* 1471. Parts; but it is plain that the Air does preſs in that Manner *. If
1473. you take away the Air on one Side, the Preſſure is ſenſible on the oppoſite Side.

Experiment 5.

2093. If the Tube A B, in which Mercury is ſuſtain'd at the Height *f*
Pl.63.F.1. by the Preſſure of the Air, whilſt the upper Part is left empty *, be
* 2085. raiſed a little, ſo that it's End may remain immerſed, it reſiſts very much; if, the Mercury being thrown out, the Tube contains Air, it only reſiſts by it's Weight, when it is lifted up.

2094. The Mercury cannot load the Tube; for it's Action againſt the Sides of the Tube is horizontal: But the Air acts againſt the upper Part of the Tube, and the Column, which is ſuſtain'd by the Tube, is of equal Weight with the Column of Mercury, contain'd in the Tube. If, the Mercury being taken away, the Air be let in, as only the Tube loads the Hand, it appears, that the Action of the Air againſt the lower Surface of the upper Part of the Tube, deſtroys the Action againſt the outward Surface of the ſame Part of the Tube, and that the Air preſſes equally upwards and downwards.

2095. By this Experiment alſo, thoſe Things are confirm'd, which are ſaid concerning the Gravity of the Air.

CHAP. II.

Of the Elaſticity of the Air.

2096. WE have ſeen, that the Air has the Properties of other Fluids;
* 2075. but beſides, it has another Property, as was ſaid *; which is, that it can take up a greater or leſs Space, according as it is compreſs'd with a different Force; and, as ſoon as that Force is diminiſh'd, it expands itſelf. By Reaſon of the Analogy of this Effect with the Elaſticity of Bodies, this Property of the Air is call'd it's Elaſticity, and the Fluids, which have it, are call'd elaſtic Fluids, as has been already ſaid.

That *the Air may be compreſs'd*, appears from an Experiment already mention'd *. *And* that *it may be dilated*, is prov'd from the following one. 2097. * 24.

EXPERIMENT 1.

Take the Tube A B cloſed at the End A, and pour Mercury into it, ſo that there may be ſome Air left in the Tube, which, when in the State of the external Air, will take up the Space A *l*; if the End B of the Tube be immers'd into Mercury, the Mercury in the Tube will deſcend to *g*, and there remain. The Height *i g* differs very much from the Height of the Mercury in the firſt Experiment of the foregoing Chapter. 2098. Pl.63.F.4.

This Difference does not ariſe from the Weight of the Air in the Tube; for its Weight is too little to produce any ſenſible Difference in the Height of the Mercury; therefore the Action of the Air upon the Mercury muſt be attributed to another Cauſe. 2099.

The Force, by which the common or external Air is compreſs'd, is the Weight of the whole Atmoſphere, which is equal to a Pillar of Mercury of the Height *h f (Fig.* 1.); therefore the compreſſing Force may be expreſs'd by this Height. But now the Preſſure of the Atmoſphere exerts two Effects, it ſuſtains the Pillar of the Mercury *i g*, and acts upon the Air in the Tube. *If the Force, by which the Mercury is ſuſtain'd*, at the Height *g i*, *be ſubſtracted from the Preſſure of the whole Atmoſphere*; that is, if the Height *g i* be taken from the Height *h f*, *there remains the Force by which the Air is compreſs'd in the upper Part of the Tube.* 2100.

This Air reſiſts with the ſame Force, and preſſes downwards *: but it can't reſiſt, unleſs it be retain'd *, and extends itſelf to A, and takes up the whole Space A *l*. * 361. * 362.

But we find by Experiments, that *the Air dilates itſelf, in ſuch Manner, that the Space, occupied by it, is inverſly as the Force, with which it is compreſs'd.* 2101.

A MACHINE,

Whereby the Dilatations of the Air, as alſo the compreſſing Forces, are compar'd with one another.

The Iron Pipe A B, three Foot long, whoſe Bore is three Quarters of an Inch, and which is clos'd at A, is at B put into the Wooden Cylinder C, joined to the Box or Veſſel D, and is there faſten'd, the Diameter of the Veſſel is about four Inches, and it's Height almoſt equal to it's Diameter. The Pipe is fill'd with Mercury in ſuch manner, that it may be about half an Inch high in the Veſſel. 2102. Pl.63.F.5.

The

The Pipe, with the Veſſel join'd to it, is applied to a Board or Frame E F G; the Surface of which has a Groove in it, to receive the Pipe, and the Board is perforated in the Place, that anſwers to the Veſſel and the Cylinder.

The Surface of the Part F G of the ſame Board is alſo hollow'd before to receive the Ruler of Box L M, which is moveable in this Cavity in ſuch manner, that it may be fix'd at different Heights, by means of a Screw, join'd to the Ruler, behind, at the Diſtance of ſix Inches from the End L, and which goes thro' a Hole in the Board.

A Copper Plate *r s* is join'd to the Side of the Ruler of Box, and made faſt. The Breadth of the Plate exceeds the Thickneſs of the Ruler a quarter of an Inch, ſo that the Plate ſtands out beyond it, making a Right Angle with the Surface of the Ruler.

Along this Prominence is mov'd the Piece *n*, join'd to the Index *q*; this is faſten'd by the Screw *o*, and is repreſented by itſelf at O N Q.

2103. We uſe moreover a Glaſs Tube, a little more than three Foot long, and which is clos'd at one End; part of this is filled with Mercury, ſo as not to exclude all the Air. The open End, the Tube being inverted, is immerg'd in Mercury, contained in the
* 2098. Veſſel and Iron Pipe, as in the foregoing Experiment *.

As this Glaſs Tube is leſs or more thruſt into the Pipe, the upper Part of the Tube, that has no Mercury in it, is greater or leſs; and is meaſur'd, if we apply this Part to the Ruler L M, which has a Groove in it, to receive this Tube, and is divided into ſmaller Parts, which anſwer to equal Parts of the Capacity of the Glaſs Tube.

2104. If this Tube ſhou'd be exactly cylindrical, theſe Diviſions wou'd be equal, but as this ſeldom happens, I ſhall ſhew how the Diviſions of the Ruler are mark'd.

The Tube P V is inverted, and applied to the Ruler, ſo that the external Surface of the End V of the Tube, may agree to the end L of the Ruler. A ſmall Quantity of Mercury is pour'd in, whoſe Height, for Example, in the Tube, is equal to a quarter or a third of an Inch, and the Height, to which it comes, is mark'd on the Ruler; an equal Quantity of Mercury is again pour'd in, and a ſecond Diviſion is mark'd; and by continuing to do thus, the whole Ruler may be divided. The equal Quantities of Mercury are had, by weighing them.

2105. But it is tedious and difficult, to ſeparate ſo many ſmall Parts of Mercury in ſuch Manner, that they may all be exactly of the ſame

Weight; therefore, if the Tube be regular, that is, if it be a Portion of a truncated Cone, as often happens, and differs little from a Cylinder, which is eaſily had, we may make uſe of another Method; becauſe in this Caſe the Diviſions are very nearly in arithmetical Progreſſion.

The firſt four or five Diviſions are to be mark'd, by the Method ſhewn; becauſe whilſt the Tube is hermetically ſeal'd it does not keep the regular Figure: Then ten, or twelve Times the Quantity of Mercury is pour'd into the Tube, and the Diviſion is mark'd; this is diſtant ten, or twelve ſmaller Parts from that laſt mark'd; and by continuing to do thus, the reſt of the Ruler is divided in the ſame Manner into ſuch greater Parts, denoting equal Portions of the Capacity of the Tube. Then theſe greater Diviſions are ſubdivided geometrically in ſuch Manner, that all the ſmaller Diviſions are in arithmetical Progreſſion continued.

But we muſt firſt examine, whether the greater Diviſions mark'd are in arithmetical Progreſſion, if they are not, the geometrical Diviſion can't take place, by Reaſon of the Irregularity of the Tube.

Experiment 2.

We muſt firſt of all meaſure exactly the Height, at which the Mercury is ſuſtained in the *Torricellian* Tube *, whoſe upper End is well clear'd of Air. * 2106. * 2085.

Such a Quantity of Air as you pleaſe is left in the glaſs Tube, before it is immers'd in the Mercury *. * 2103.

This Tube is put into the Mercury as far as you pleaſe alſo, and the Ruler L M is faſten'd in ſuch Manner, that the End L may agree to the Surface of the Mercury in the Glaſs Tube. But the Index *q* is applied to the upper End of the ſame Tube, and anſwers to the Diviſion of the Ruler, denoting the Space L V, which is taken up by the Air in the Tube. The Height of the Point L. above the Surface of the Mercury in the Veſſel, is meaſur'd in Inches and ſmaller Parts, and is ſubſtracted from the Height of the Mercury in the *Torricellian* Tube, and the Difference expreſſes the Force, that compreſſes the Air in L M *. The Situation of the Glaſs Tube is changed, the ſame Air remaining in the Tube, and the Force is meaſur'd again, which compreſſes the Air, as alſo the Space taken up by the Air. Then the Spaces taken up will be inverſly, as the compreſſing Forces. * 1100.

Let the Height of the Mercury in the Barometer be 29,25 Inches; the Height of the Point L above the Surface of the Mercury in the Veſſel 2107.

Veſſel 20,25 Inches; and L V 32 Parts. Now if the Glaſs Tube be drawn out of it's Sheath more, L is raiſed up; when the Height of this Point comes to 24,75 Inches, L V is 64 Parts. The compreſſing Forces are 9. and 4,5; the Spaces taken up 32, and 64.

This Experiment may very well be varied many Ways.

The ſame Rule obtains in compreſs'd Air.

EXPERIMENT 3.

2108. Pl.63.F.6. Take a Curve Tube ABCD open at A, and clos'd at D; let the Part BC be fill'd with Mercury, ſo that the Part CD may contain Air of the ſame State or Tenor as the external Air; therefore, the compreſſing Force is the Column of Mercury, whoſe Height is *hf (Fig. 1.)* and by this Height muſt this Force be expreſs'd, as in the foregoing Experiment; but the Space taken up by the Air is CD. Pour Mercury into the Tube AB, that it may riſe up to *g*, the Air will be reduc'd to the Space *e* D: Now the compreſſing Force is equal to a Column of Mercury of the Height *f g*, and alſo the Preſſure of the external Air upon the Surface *g* of the Mercury; this Force is expreſs'd by the Sum of the Heights *f g* in this Figure, and *hf* in Fig. 1. This Sum is always to *hf (Fig. 1.)* as CD to *e* D; and again the Forces are inverſly as the Spaces.

2109. *The Elaſticity of the Air is as it's Denſity*; for this laſt is as the * 1464. Space taken up by the Air *, and therefore as the Force compreſ- * 2101. ſing the Air *; which is equal to that by which the Air endeavours * 361. to expand itſelf *; but this Force is it's Elaſticity.

2110. Hence it follows, that the Air in which we live is reduced to the Denſity which it has near the Earth, by the Preſſure of the ſuper-incumbent Air, and that it is more or leſs compreſſed, according to the greater or leſs Weight of the Atmoſphere; for which Reaſon alſo the Air is leſs denſe at the Top of a Mountain than a Valley, as being compreſs'd by a leſs Weight.

2111. *The Force, by which the Particles of the Air fly from each other, encreaſes in the ſame Ratio, as the Diſtance between the Centers of the Particles is diminiſhed.* That is, that Force is inverſly as this Diſtance.

2112. Pl.63.F.7. To demonſtrate which, let us conſider two equal Cubes A and B, containing unequal Quantities of Air; let the Diſtance between the Center of the Particles be as 2 to 1, the Numbers of the Particles will be in the ſame, but inverſe Ratio, in the Lines *de* and *hi*; the Numbers of the Particles acting upon the Surfaces *dg* and *hm* are, as 1 to 4, namely, as the Squares of the Numbers of the Particles in

in equal Lines, and as the Cubes of thoſe Numbers, that is, as 1 to 8, ſo are the Quantities of Air contained in the Cubes; in which Ratio alſo are the Forces compreſſing the Air in the Cubes *. The Forces acting upon the equal Surfaces *dg* and *hm* are as the Forces by which the Air is compreſſed *; they are alſo in a Ratio compounded of the Numbers of the Particles acting, and the Action of all the Particles; therefore, this compound Ratio is the Ratio of 1 to 8: The firſt of the compounding Ratios, as has been ſaid, is that of 1 to 4; wherefore, neceſſarily the ſecond is that of 1 to 2, which is the inverſe Ratio of the Diſtance between the Particles. And this Demonſtration is general; for by 1 and 8 we expreſs any Cubes whatever; by 1 and 4, the Squares of the Cube Roots; and laſtly, by 1 and 2, the Roots of thoſe Cubes.

* 2109. 361. * 361.

This Demonſtration proves that the Action, which the Particles continually ſuffer from all Sides, is encreaſed in the Ratio, in which the Diſtance between the Centers of the Particles is diminiſhed. 2113.

But Experiments ſhew that the Particles do not extend their Action to Particles, remov'd to a ſenſible Diſtance; whence it appears, the ſame Denſity of Air being ſuppos'd, that there is not a greater Elaſticity, where there is a greater Quantity of Air. 2114.

The Effects of the Elaſticity of the Air are like thoſe of it's Gravity, and included Air acts by its Elaſticity, juſt as Air not included does by it's Weight. 2115.

The Air which is loaded by the Weight of the whole Atmoſphere, preſſes every Way from the very Nature of Fluidity *; and the Force which it exerts, does no Way depend upon the Elaſticity, becauſe, whether you ſuppoſe Elaſticity, or not, that Force which ariſes from the Weight of the Atmoſphere, and is equal to it, can be no Way changed. But, as the Air is elaſtic, it is reduced to ſuch a Space by the Weight of the Atmoſphere, that the Elaſticity, which reacts againſt the compreſſing Weight, is equal to that Weight *. But the Elaſticity encreaſes and diminiſhes as the Diſtance of the Particles diminiſhes or encreaſes *, and it is no Matter, whether the air be retained in a certain Space by the Weight of the Atmoſphere, or any other Way; for in both Caſes it will endeavour to expand itſelf with the ſame Force, and preſs every Way. Therefore if the Air near the Earth be incloſed in any Veſſel, without altering it's Denſity, the Preſſure of the included Air will be equal to the Weight of the whole Atmoſphere.

* 1418. * 361. * 2109.

EXPERIMENT 4.

2116. The *Torricellian* Tube is encloſed in the Glaſs D R, ſo that the
Pl.68.F.1. Air, which preſſes upon the Surface of the Mercury, contained in the Veſſel V, may have no Communication with the outward Air; by the Elaſticity of the Air the Mercury is ſuſtain'd at the ſame Height in the Tube, as in the open Air.

The Tenor of the Air continuing the ſame, what we have ſaid will always obtain; but this Tenor or Temper of the Air is not
2117. always the ſame; *the repellent Force of the Particles is often encreas'd, or diminiſh'd, though the Diſtance between the Centers is not chang'd*;
* 2123. I ſhall ſpeak of this Alteration in the following Chapter *; in the following Part of this Book we ſhall alſo ſee, That the Elaſticity encreaſes by Heat, and diminiſhes by Cold.

I ſhall deliver ſome other Experiments, concerning the Elaſticity of the Air, in the fifth Chapter of this Book.

CHAP. III.

Of ſome other elaſtic Fluids.

2118. THERE are ſeveral Fluids, which have the ſame Property as the Air, Elaſticity.

Among theſe Vapour is remarkable, of which we treat in the tenth Chapter of this Book.

2119. *By Fermentation, Effervеſcence, Putrefaction, and Combuſtion, elaſtic Fluids are ſeparated from Bodies*, which are different according to the Difference of the Bodies.

2120. *Such a Fluid ariſes from many Bodies, when the Preſſure of the external Air is diminiſhed, or taken away.*

2121. *This is alſo obſerv'd in ſome, when they are only moiſten'd.*

But in theſe two laſt Caſes there is no Separation without Effervеſcence.

All theſe Fluids, except Vapour, how different ſoever one from
2122. another, are commonly expreſs'd by the ſame Name Air. But as *the Air* is that Fluid, *with which the whole Surface of the Earth is encompaſs'd*, this, properly ſpeaking, *is a Mixture made up of various elaſtic Fluids, in which innumerable Corpuſcles of different Sorts float.*

* 1476. Theſe Corpuſcles aſcend to different Heights *, according to their
1477. different ſpecific Gravity: and the Exhalations of different Bodies alſo, which are elaſtic Fluids, are rais'd differently in the Air.

Whence we infer, that *the Air in a high Place does not differ from the lower Air in Denſity only.* 2123.

It cannot be doubted that different elaſtic Fluids have different Properties; which alſo appears from Experiments; for the Effect of different Exhalations differ from one another. 2124.

Whilſt the Parts, which, being ſeparated from Bodies, make elaſtic Fluids, remain in the Bodies, they are join'd together, or adhere to other Parts of the Bodies; wherefore, they *can't be rank'd among elaſtic Fluids* any more, than Water, before it is turn'd into Vapour, can be call'd Vapour. 2125.

But the Space taken up, by the Matter which becomes elaſtic, is very ſmall, whilſt it remains in the Bodies themſelves, if it be compar'd with the Space, which it takes up, whilſt it exerts it's Elaſticity, the external Compreſſion being ſuppos'd equal in both Caſes. 2126.

This plainly appears in thoſe Bodies, which are wholly turn'd into an elaſtic Fluid. Ice a ſolid Body, whoſe Parts cohere, is firſt turn'd into Water, in which the Coheſion is leſs, then into Vapour, an elaſtic Fluid; this takes up a Space at leaſt fourteen thouſand times greater, than when it was Water; and this too whilſt the Vapour is compreſs'd by the Weight of the whole Atmoſphere; in thoſe very Places from which it excludes the Air: and who does not ſee that this Expanſion may be immenſely encreas'd, by taking away the Preſſure of the Atmoſphere? 2127.

I ſhall make ſome other Obſervations concerning Water; an elaſtic Fluid may be ſeparated from it without a ſenſible Diminution of it's Bulk; which Separation is made by Cold, Heat, or by taking away the Preſſure of the Atmoſphere. 2128.

We obſerve this Separation to be very ſudden, if all the Preſſure be ſuddenly taken away.

Experiment 1.

The Glaſs Veſſel A B is exactly fill'd with Water; at the End B a Braſs Cylinder is join'd to it, that the Syringe, which is repreſented in Fig. 1. Pl. 71. may be join'd to it, by Means of a Screw. 2129. Pl.63.F.8.

Whilſt the Piſton of the Syringe is drawn out, the Water deſcends into the Syringe by it's Weight; and there is a Space in the upper Part of the Veſſel void of Water and Air. Immediately alſo innumerable Bubbles of an elaſtic Fluid, ſhew themſelves at the ſame Time; and all the Water looks white with theſe Bubbles.

This elaſtic Fluid differs from the Air, with which the Surface of the Earth is encompaſs'd, though it be in the Air in great Quantity. 2130.

EXPERIMENT 2.

2131. If a Phial be filled with Water, from which every elaſtic Fluid has been driven out, by Fire, or otherwiſe, and a ſmall Bubble of Air being left, the Phial be inverted, and the open End of it be immers'd into Water, contain'd in any Veſſel, this Bubble of Air, in ſome Days, will enter into the Water wholly, and ſeveral Bubbles will be ſucceſſively abſorb'd as it were by the Water in the ſame Manner. But with Reſpect to every one of the Bubbles it is to be obſerv'd, that a much greater Part of the Bubble enters into the Water the firſt Day, than there does in the following Days.

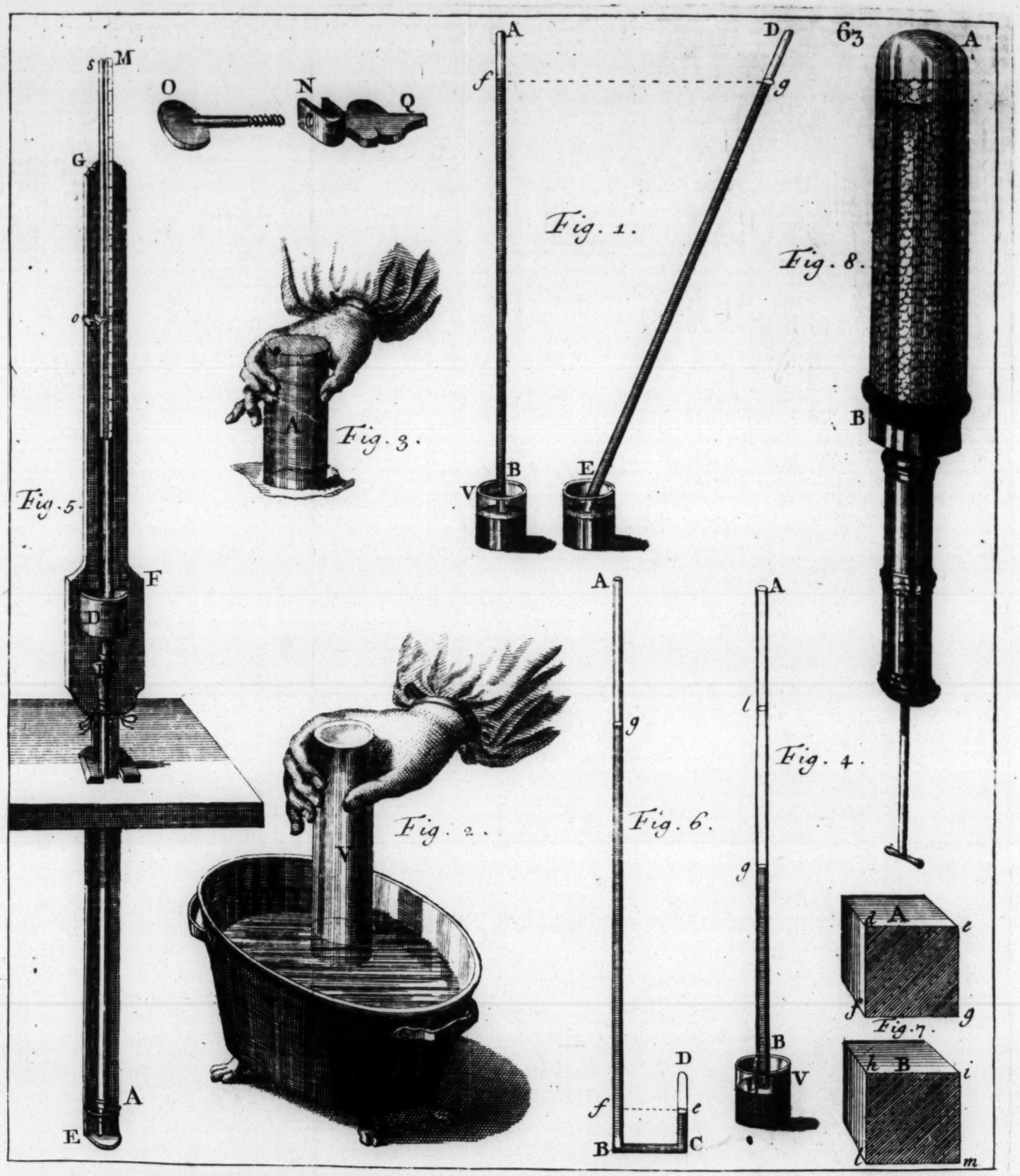
2132. From this Experiment we infer that there are ſome Parts in the Air, which enter into the Water more eaſily than others, and remain there.

Whence it follows that, whilſt Water is expos'd to the open Air, there enters into it a greater Quantity of that Matter, which gets into it more eaſily; and that the Air, that has enter'd into it, differs from the external Air. We obſerve alſo that this Fluid often dilates itſelf more, when the Preſſure is diminiſh'd, than according to the Rule of Number 2101. But the Expanſion of this Fluid is immenſe.

2133. This Fluid takes up a very ſmall Space in the Water; for, as was ſaid above, the Separation is made without any ſenſible diminution of the Bulk of the Water, and *Mariotte* mentions an Experiment concerning the Dilatation of this elaſtic Matter, whereby it appears, that this Matter, which was driven out from the Water, when it had loſt it's Heat, and ſuſtain'd the Weight of the whole Atmoſphere, took up ten times the Space, that the Water did, in which it had been contained.

2134. In the fifth Chapter of this Book we ſhall ſee *, how much this
* 2196. Fluid can be dilated; if it expands itſelf ten thouſand times only, it's Space will be an hundred thouſand times greater than the Space taken up by the Water from which it went out. But who ſhall determine how great the Expanſion is, if we have Regard to the Space taken up in the Water by this elaſtic Matter?

2135. Hence we infer, that *the Particles of elaſtic Fluids* are not of the ſame Nature with other elaſtic Bodies; for all the Particles cannot be encreas'd, as the whole Bulk is encreas'd, the Surface, in every Degree of Expanſion, being kept free from all Irregularities and Angles, for in Expanſions the Parts are eaſily mov'd amongſt themſelves: Whence it follows, that the Particles *do not touch, tho' they*


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Fig. 3.
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Fig. 1.
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Fig. 4.
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Fig. 8.
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Fig. 7.
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they repel one another, a like Property of Particles has been taken Notice of above *. * 75. 87.

CHAP. IV.

Of the AIR-PUMP.

THE Elaſticity of the Air is the Foundation of the Conſtruction of a Machine, by which the Air may be drawn out of any Veſſel. This Machine is called an *Air-pump*, which is made ſeveral Ways. 2136.

The chief Part in all of them is a Barrel, or hollow Cylinder of Metal, poliſh'd in the Inſide; in this Barrel muſt move a Piſton, that fills it's Bore ſo exactly as to let no Air ſlip by. This Piſton is thruſt down cloſe to the Bottom of the Barrel, and then rais'd up in ſuch a Manner as to exclude all the Air from the Cavity of the Cylinder or Barrel; if this Cavity communicates with any Veſſel, by Means of a Pipe at the Bottom of the Barrel, the Air in the Veſſel will expand itſelf, and Part of it will enter into the Barrel, ſo that the Air in the Barrel, and in the Veſſel, will have the ſame Denſity. Shut up the Communication between the Veſſel and Barrel, and letting the Air out of the Barrel, apply the Piſton cloſe to the Bottom. If you raiſe the Piſton a ſecond time, and open the Communication between the Barrel and Veſſel abovementioned, the Denſity of the Air in the Veſſel will again be diminiſh'd; and repeating the Motion of the Piſton, the Air in the Veſſel will be reduc'd to the leaſt Denſity. Yet all the Air can never be exhauſted by this Method; for at every Stroke the Air does ſo expand itſelf, as to have the ſame Denſity in the Barrel as in the Veſſel; in which laſt therefore, there is always a little Air left.

But after the Elaſticity is diminiſh'd, as much as poſſible, by repeating the Operations, we ought not from hence to make a Judgment of the Denſity, as in ſmaller Dilatations *. This Elaſticity of the remaining Air is not always the ſame, and it is not ſenſibly diminiſh'd by the Dilatation of it, as we ſhall find in the following Chapter *. 2137. * 2109. * 2191.

All Air-pumps have in common the Parts above deſcrib'd, but they differ in ſeveral other Things. Firſt, the Communication between the Receiver to be exhauſted, and the Cylinder or Barrel, is open'd and ſhut different Ways. Secondly, there are different Ways of getting the Air out of the Cylinder or Barrel, when the 2138.

Piſton is brought to the Bottom. Thirdly, the Piſtons differ in different Pumps. Fourthly, the Poſition of the Cylinder is not the ſame in all Pumps. Fifthly, there are different Contrivances for moving the Piſton. Laſtly, there are often two Barrels, in one of which the Piſton is rais'd, when it is depreſs'd in the other.

Pl. 64. Our Pump is here repreſented; the oppoſite Part of the Box, or Caſe, the Door being ſhut, which belongs to that Part, is ſeen in Fig. 1. Plate 68. I ſhall defer the particular Deſcription of it to another Place, and only here mention ſome Things in general.

The AIR-PUMP.

2139. The fore Part of the Pump is repreſented in Plate 64. the Doors
Pl. 64. of the Box, in which it is encloſed, being taken away.

Pl. 65. The hinder Part of the ſame Pump, taken out of it's Box, is repreſented in Plate 65. The ſame Parts are mark'd with the ſame Letters in each Figure.

This Pump has two Barrels A, B, in each a Piſton is mov'd, whoſe Parts are repreſented ſeparately at C, D, E, and F.

2140. To the lower Plate of the Part D, there is joined a ſmall ſquare Tube *d*, to whoſe Cavity the Hole *n* in the Plate anſwers.

This ſmall Tube goes through the Cylinder F of Cork, which is retain'd by the Plate E, with which the ſolid Piece *g* coheres, which goes into the ſmall Tube *d*, and is faſten'd by the Screw *e*, which goes into the ſolid Piece, and whoſe Head at *n* covers the Hole, which anſwers to the Tube *d*. Between the Plate E and the Cork F a thin Piece of Leather *f* is faſten'd, which is prominent every Way, and which, whilſt the Piſton is thruſt into the Cylinder, applies itſelf to the lateral Surface of the Cork. This Method is uſed in *England*. This Leather ſhou'd be ſoak'd in Oil and Water, as was ſaid in N. 1436.

The Piſtons before they are thruſt into the Barrels, ſhould be left in Water ſome Hours, and well oil'd. A ſmall Quantity of Water muſt be pour'd into the Barrels upon the Piſtons.

2141. We make uſe of Calf's Leather, we apply the Epidermis to the Cork; but Care muſt be taken, that the Piſton exactly fills the Barrel, but yet ſo, that the Leather may not be compreſſed too much; for if it be made dry, whilſt the Oil and Water are ſqueezed out by a too great Compreſſion, the Piſtons will not retain the Water, when it ſuſtains the whole Preſſure of the Atmoſphere. But when the Leather is of a due Thickneſs, we may make uſe of the Pump two or three Months, without once taking out

out the Piſtons: Which yet we ſhould not neglect, when, the Oil being grown thick, the Leather adheres to the hollow Surface of the Barrel, and the Piſtons are mov'd with Difficulty: Then they muſt be taken out; the Leather muſt be ſeparated a little from the Cork, and well oil'd, and the Piſtons muſt be left ſome Hours in Water.

The Tail C of the Piſton has Teeth, as in moſt Air-pumps; it's lower End *c* is cylindrical. This cylindrical Part paſſes through a cylindrical Cavity in the Prominence *p* of the Piſton; the Diameter of this Cavity exceeds the Diameter of the Cylinder *c* but a little, and the Tail C may be rais'd, and depreſs'd, three Quarters of an Inch, the Piſton itſelf remaining unmov'd. 2142.

Both Piſtons are mov'd by turning the Wheel R, whoſe Motion, whilſt it goes and comes, wants ſomewhat of the third Part of a Circle. Pl. 64. 65.

The Veſſels to be exhauſted are put upon the Plate G, and this communicates by the Pipe XXX with the Barrels. For there is a Cavity under the Plate C, which anſwers to the Pipe II, in which there are two Cocks, Y, Z, between which the Pipe XX is join'd to this Pipe which communicates with them, under the Plate, upon which the Barrels ſtand. 2143.

There is a Cock under the Bottom of each Barrel; the Tails of theſe Cocks are ſeen at L, L, which are join'd by the Braſs Ruler P P in ſuch Manner, that by the Motion of this Ruler both the Cocks may be mov'd at the ſame Time. To the Axis of the Wheel R, behind, is join'd an Iron croſs Piece H N M, whereby theſe Cocks are mov'd. 2144.

In the Poſition, in which the Parts of the Machine are repreſented in this Figure, the Barrel B communicates with the Veſſel to be exhauſted; the Barrel A with the external Air; and, by depreſſing the Piſton of this Barrel, all the Air is forc'd out of it, and in the mean Time the other Piſton is rais'd higher.

The Air, which is forc'd out of the Pump, goes out through the Cock at *l*, where there is a Prominence, that a ſmall Valve made of Leather may cloſe the Hole. This Valve hinders the entring in of the external Air, and we may do without it; but it very much leſſens the Labour. 2145.

When the Piſton comes to the Bottom of the Pump A, the End N of the Croſs paſſes over the Roller *v*, which it depreſſes, raiſing the End S of the ſmaller Iron Ruler S V, which moves about the Tail *o*, which coheres with it, and goes through the Cylinder O in the 2146.

the Middle of the Ruler P P, join'd to it; S V immediately returns to it's former Poſition, and in that very Moment the Piſton is applied to the Bottom of the Pump.

2147. The Motion of the Wheel is now to be directed towards the contrary Part. In the Return of the Croſs the End N runs againſt the Roller *v*, and drives it on; 'till this Roller is ſo depreſs'd, by turning the Cocks L, L, that N paſſes over it.

In this turning of the Cocks, L, L, they deſcribe Arches, of ninety Degrees; and the Communication of the Barrel B with the Veſſel is ſtopp'd, and a new Communication with the external Air is open'd; the contrary to this obtains in reſpect of the Barrel A.

During this Motion of the Cocks, C is indeed raiſed, but the Piſton itſelf remains at the Bottom of the Barrel A; which is neceſſary leſt the external Air ſhou'd again enter into the Barrel, and
* 2142. which how it is done has been ſaid above *.

Now if the Motion of the Wheel be continued, the Piſton of the Barrel A is raiſed up, which communicates with the Veſſel to be exhauſted, and the Air is forc'd out from the Barrel B, and the End M of the Croſs paſſes over the Roller *v*, and what was explained in the contrary Motion, obtains in this Caſe, in the ſame Manner.

2148. The Wheel is turn'd by the Handle *m m*, which is about two
Pl. 64. Foot long; this is in an horizontal Poſition, when the Ends M, and N, of the Croſs, are alſo in an horizontal Line.

2149. When in this Motion it happens, that there is a greater Reſiſtance, when the Cocks are mov'd, than in the reſt of the Motion, this is a Sign that the Cocks want to be rubb'd with Oil and Wax; which in hot Weather ſhou'd be repeated, when the Machine has been in continual Motion, for three or four Hours.

2150. As to the Cocks Y, Z, above-mentioned *, by the firſt the Com-
* 2143. munication between the exhauſted Veſſel and the Barrels is ſtopp'd, when the Air is exhauſted; by the other, the Air is again let into the Veſſel, and the Communication with the mercurial Gage is cut off.

2151. This mercurial Gage is repreſented at Q; it's Uſe is to determine the Quantity of Air exhauſted from the Veſſel, as alſo the Quantity of Air that remains in it; by this alſo the Capacities of Veſſels to be exhauſted are meaſur'd; which is of Uſe in many Experiments. Mine differs from the common Gages.

2152. There is a Pipe at K that has a Hole at it's upper End, and a Screw at it's lower End, it goes into the Plate G, and the Air paſſes through it into the Pump.

In

In the ſame Manner, a ſmall Cylinder, with a Screw upon it, is frequently join'd to the Plate of the Pump, whereby a Globe, or any other Veſſel to be exhauſted, may be applied to the Machine; which is commonly done by putting a Cock between, that the Veſſel when emptied of the Air may be ſeparated from the Pump. 2153.

In the Middle of the Plate G there is a Hole at *a*, whereby ſeveral Machines may be joined to the Plate; and which is clos'd by a Screw. 2154.

By this Means alſo there is often applied to the Pump a cylindric Box, full of Leathers waxed, through the Center of which a Braſs Wire paſſes, which may be mov'd by the Help of a Handle, ſo as to communicate Motion into a Place void of Air; the Box has a Cover, which enters into it with a Screw, for preſſing the Leathers together, and the better to prevent the paſſing by of the Air. 2155.

Such a Box, or Collar of Leathers, is often join'd to the Cover which is laid over the Receivers, as may be ſeen in Fig. 3. Plate 3. and in many Plates of this Book.

When the Receivers are laid upon the Plate G, or when they have Covers, and the Air is to be kept from getting in, ſome Hours, or Days, we make uſe of a Mixture made up of four Parts of white Wax, two of Reſin, and one of Oil of Olives; in Summer leſs Oil is requir'd, in Winter more. 2156.

For a leſs Time it is ſufficient to put the Veſſels upon a Ring of thin Leather, which has been ſoak'd ſome Days in Oil; it muſt be well oil'd every Time, before it is us'd, and left in Water a Quarter of an Hour; but when the Experiments are ended, the Leather muſt be well dry'd with a Linen Cloth; and the ſame Ring may ſerve many Years, if it be kept in a dry Place. 2157.

A ſingle barrel'd Air-pump.

I ſhall briefly ſhew how many Conveniencies of our Pump, may be transferred to a leſs, and ſingle barrel'd Pump. 2158. Pl. 66.

This Pump conſiſts of one Cylinder A; which is applied to the vertical Board or Frame B B.

The Piſton is like that, which has been explained above *, the Tail of it has Teeth alſo, and is moved by Means of a Sector of a Circle which has alſo Teeth. The Motion is impreſs'd by moving the Handle *m m*, join'd to the Axis which paſſes through the Center of the Sector. * 2140.

2159. To the other End of this Axis is join'd the Iron Croſs K P O, by Means of which the Cock of the Barrel is moved, which is applied beneath the Bottom of it. L is the Tail of the Cock, which is equally extended both Ways, and to which, at the upper End of it, is join'd the Roller *v*, and the Pin *s* ſtands upon the lower End of it.

In the Poſition of the Cock, which is repreſented, there is a Communication between the Pump and the external Air, through
* 2144. an Hole at *l*, through which the Air goes out *, whilſt the Piſton is depreſs'd.

When the Piſton is but a little diſtant from the Bottom of the Barrel, M paſſes over the Roller *v*, and when it has paſs'd over, O is applied to the Part *s*, and preſſing it, it lifts up the Roller *v* a little; whereby the Poſition of the Cock is indeed alter'd, but the Way, through which the Air comes out, is not much narrow'd. In this Poſition the Piſton is applied to the Bottom, and no Air remains in the Pump.

2160. The Motion of the Sector is now directed towards the contrary Part; M runs againſt the Roller *v*, and turns the Cock, and the
* 2147. Piſton is rais'd *. When the Piſton is almoſt come to the Top of the Barrel, the Parts N and P of the Croſs act, as M and O acted, before; the Cock is turn'd anew, the Motion of the Sector being alter'd.

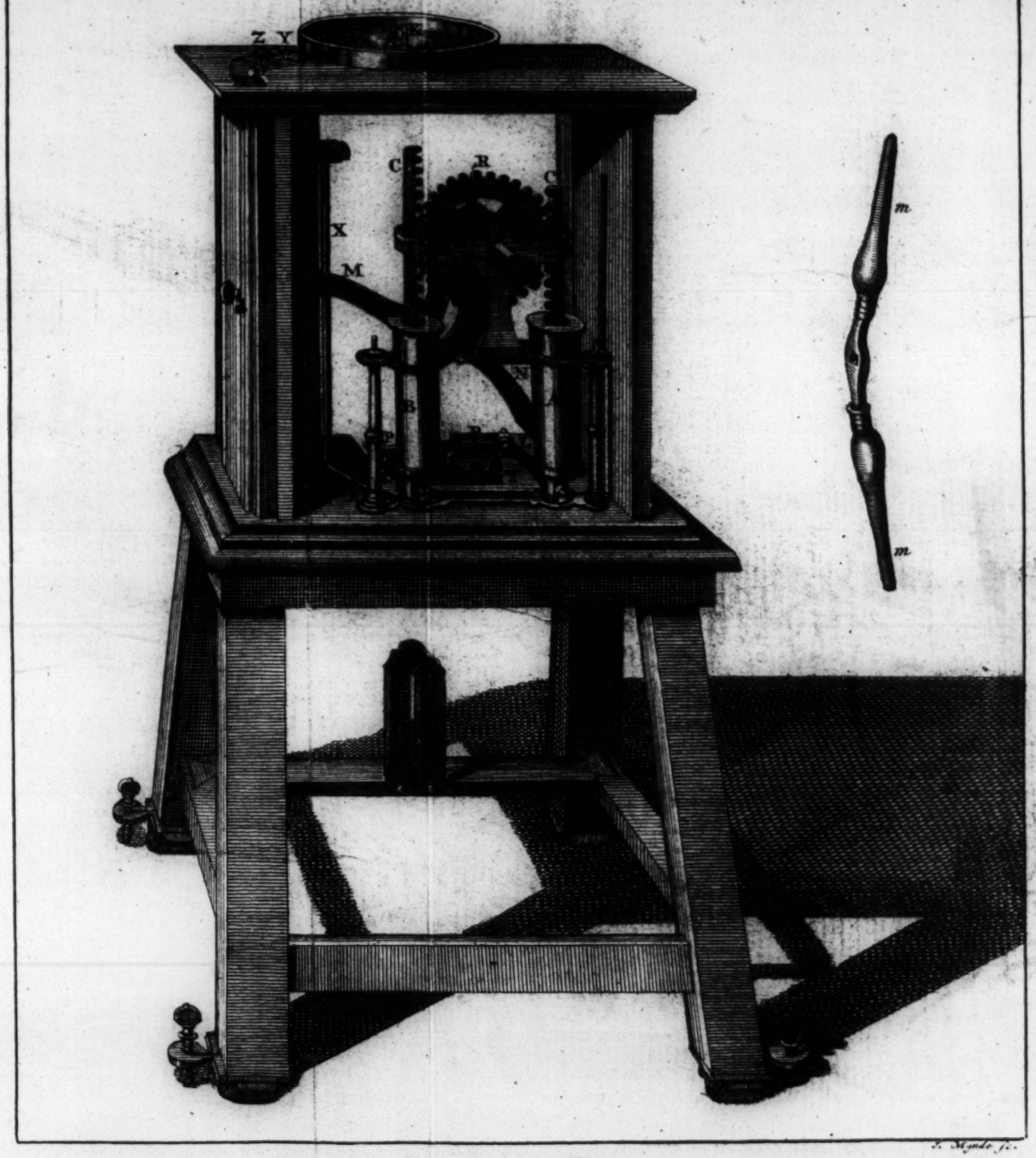
During the Aſcent of the Piſton, the Barrel communicates with the Veſſels to be exhauſted, by Means of the Pipe X X, which
* 2143. Veſſels are put upon the Plate G *, or are join'd to the Pump at
* 2153. K *.

2161. By the Cock Y the Communication between the Pump and the Veſſels to be exhauſted is ſtopp'd, and the Air is let into them again alſo.

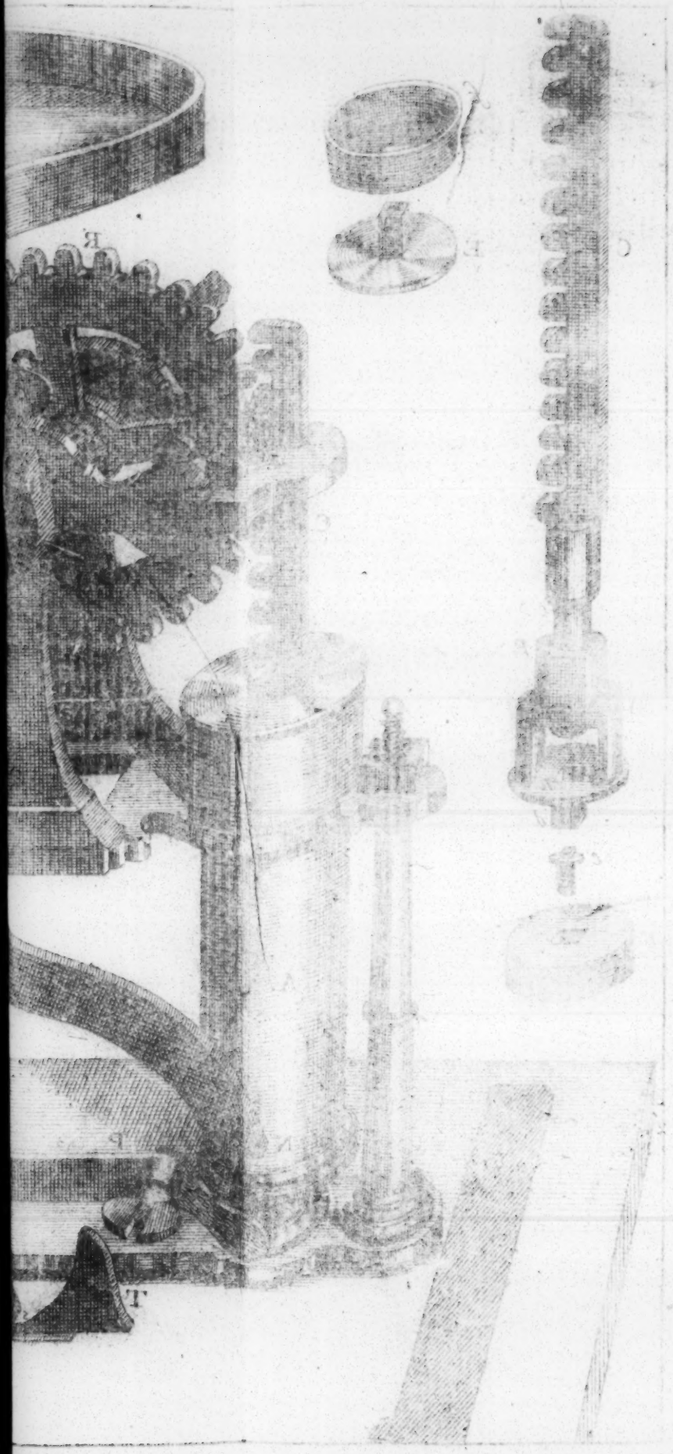
2162. The mercurial Gage Q has the Uſes already mention'd *; that
* 2151. repreſented here is a plain and ſimple one, conſiſting of a Glaſs Tube, above three Foot long, and whoſe lower End is immers'd in Mercury. The Gage repreſented in Plate 65 may be uſed here alſo.

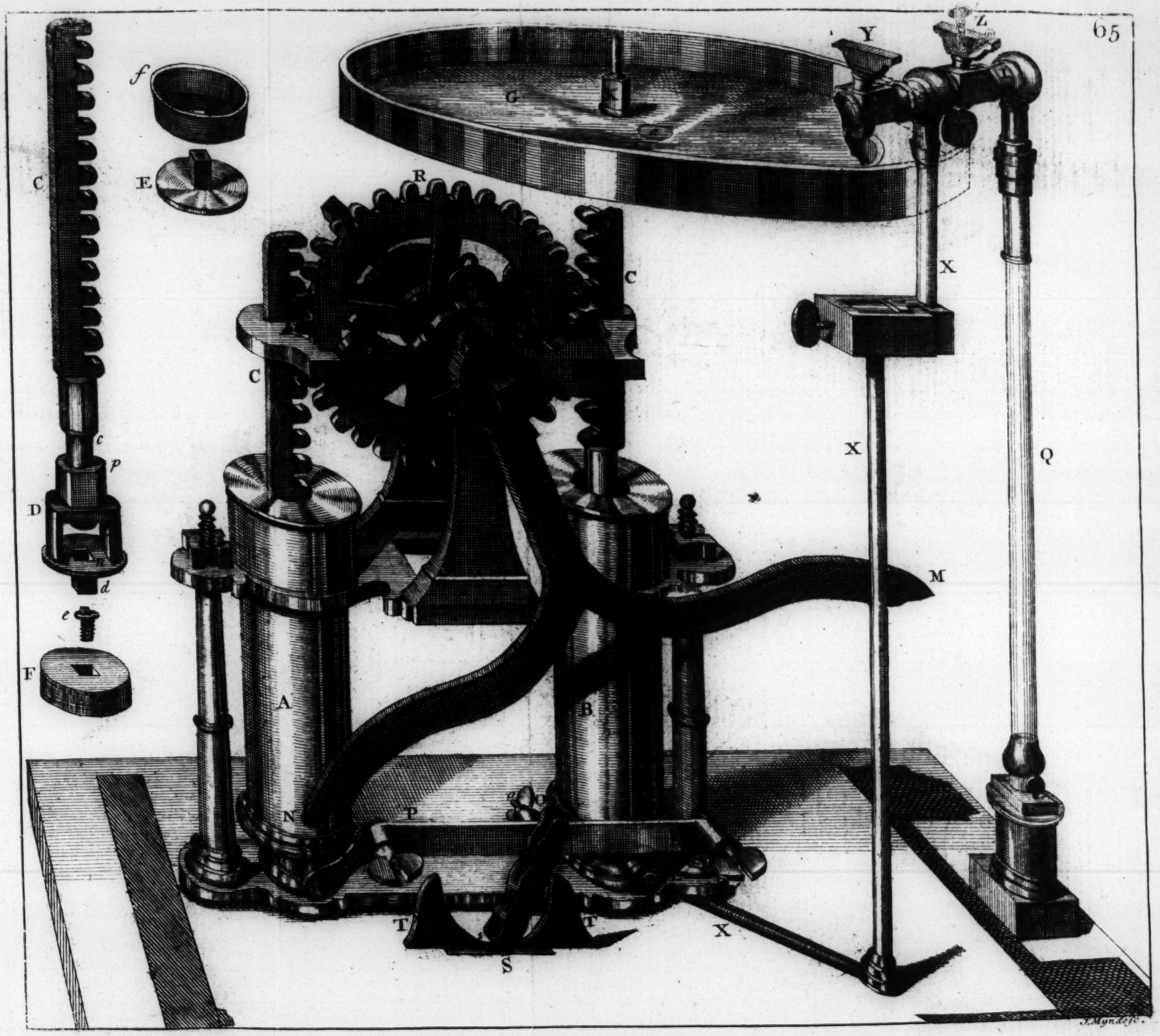
What is contain'd in Numbers, 2152, 2153, 2154, 2155, 2156, and 2157, ſhould be referr'd hither alſo.

CHAP.



J. Skynde fc.


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CHAP. V.

Several Experiments concerning the Air's Gravity, and it's Spring.

WE have ſhewn that Air is heavy *; it may be weigh'd like other Bodies, and ſo it's Denſity may be compar'd with that of other Bodies *. If the Veſſel that contains the Air be weigh'd, when it is full of Air, and again, when the Air is exhauſted, the Difference between their Weights is the Weight of the Air. But we ſhou'd make uſe of a very nice Balance. 2163. * 2084. * 1463.

EXPERIMENT 1.

Having exhauſted the Air out of the Glaſs Ball G *, whoſe ſolid Contents are 283 cubic Inches. This is ſuſpended on the Arm B of the Balance A B; Weights are put into the Scale L, to make an Equilibrium. The Cock E being open'd, the Air enters in, and the Equilibrium is deſtroy'd; but it is reſtor'd, if about an hundred Grains be added to the Weight in the Scale; ſometimes the number of Grains, which are added, is greater, and often leſs, according to the different Temper of the Air, which undergoes Alterations, from the Alteration of the Weight of the Atmoſphere, and from other Cauſes. 2164. Pl.67.F.1. * 2153.

We have ſeen that Bodies immerſed in Fluids are ſuſtain'd by them, and more or leſs according to the greater or leſs Bulk of the Body *; and the Weight loſt in that Caſe is determin'd from the known Denſity of the Fluid *. By the foregoing Experiment, therefore, it may be known, how much Bodies gravitate leſs in Air than in a Vacuum. 2165. * 1495. * 1478.

Hence alſo may be deduc'd, that *Bodies that are in Equilibrio in the Air, if their Bulks are unequal, will loſe their Equilibrium in a Vacuum*, which is confirm'd by the following Experiment. 2166.

EXPERIMENT 2.

The Copper Plate *e i* is applied to the Plate G, of the Air-pump, and is faſten'd by Means of the ſmall Tube K, whoſe Screw goes through the Plate. To this Plate at *i* there is faſten'd a ſhort Cylinder, to which the Copper Plate F H is join'd, which hinders the Bodies, made Uſe of in the Experiment, from touching the Leather Ring *, applied to the Plate G, in their Motion. 2167. Pl.67.F.2. * 2157.

At the End *e* of the ſame Plate, a thick Braſs Wire ſtands upon it, which is bent at Top, that the Plate L may be vertically join'd to it, which has a Hook at Bottom, and which can be rais'd, and depreſs'd, and fix'd by Means of the Screw *n*.

A ſmall and very exact Balance is ſuſpended upon this Hook; the Solid D of Wax and the Leaden Weight, which together with their Chains are in Equilibrio, are hung upon the Balance; and the Plate L is fix'd at ſuch an Height, that the Balance can only move a little.

All theſe Things are cover'd with the Glaſs Receiver R, and the Air being exhauſted, the Wax preponderates, it's Bulk being greater than the Bulk of the Piece of Lead P, it muſt be more ſuſtain'd by the Air; when you let the Air into the Receiver again, the Equilibrium is reſtor'd.

2168. The Elaſticity or Spring of the Air which has been prov'd in the ſecond Chapter of this Book, becomes more ſenſible by the following Experiment.

Experiment 3.

2169. Tie up a Bladder very cloſe, with a ſmall Quantity of Air in it, put a Receiver over it, and pump out the Air; thereby the Preſſure upon the External Surface of the Bladder will be diminiſhed; and immediately the Air included in the Bladder will expand itſelf, and ſwell it out.

2170. We have ſeen that the Spring of the Air is equal to the Weight
* 2115. of the whole Atmoſphere *; the following Experiment will make it viſible.

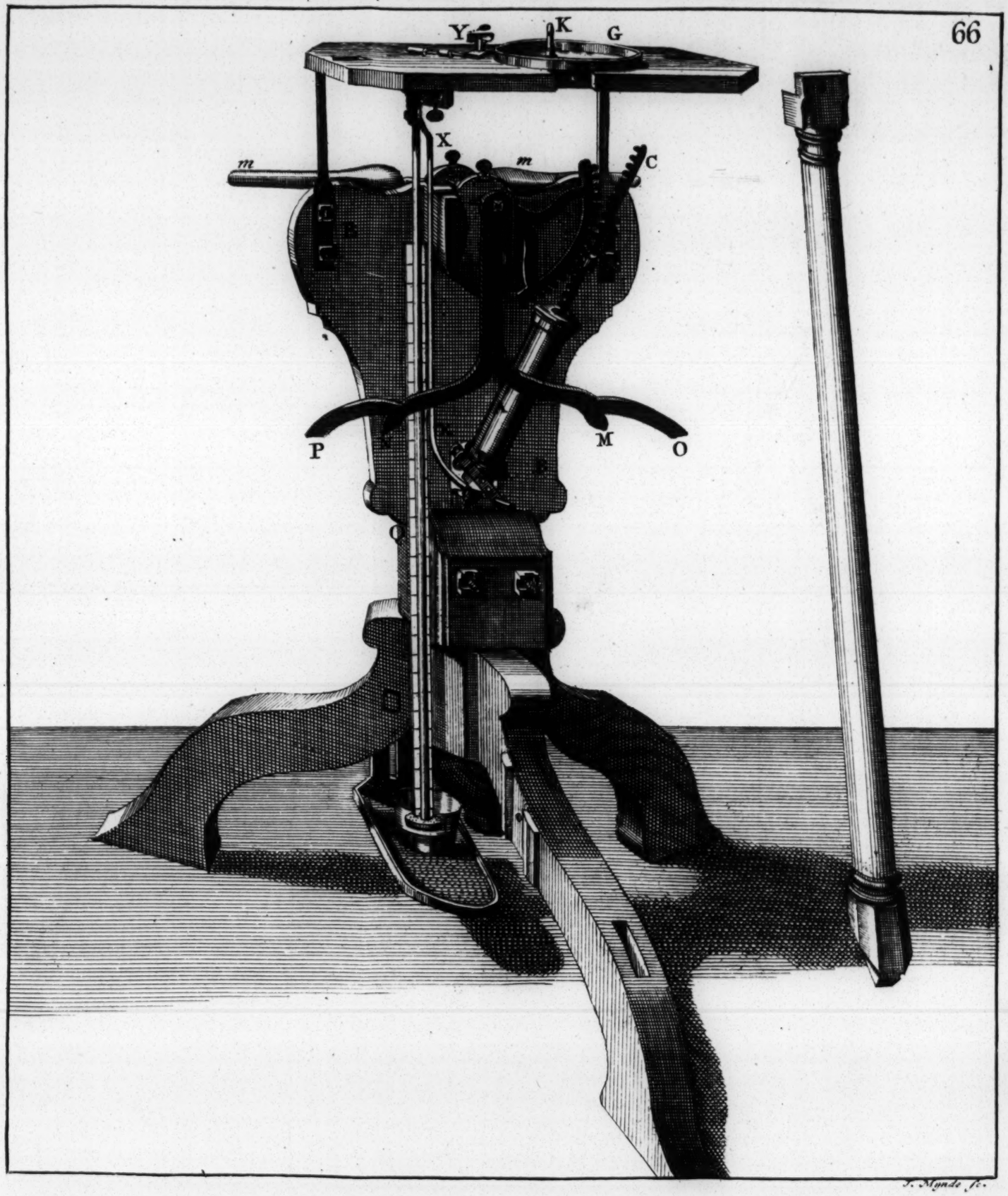
Experiment 4.

2171. Take a Bladder tied up very cloſe, and not quite full of Air, and
Pl.67.F.3. put it in the Bottom of the Wooden Box A, whoſe interior Diameter is three Inches. Put on the Leaden Weight P, which weighs forty Pounds, and goes into the Box, only leaving Room for the Bladder.

Cover the Box with a Glaſs Receiver, pretty high, that the Weight P may be raiſed an Inch high.

The Air being exhauſted, the Bladder, as in the foregoing Experiment, will ſwell out, whereby the Weight will be rais'd: if the Weight were as big again, it wou'd be rais'd in the ſame Manner.

2172. In the following Experiment we obſerve the Effects of the Gravity of the Air and it's Spring at the ſame Time.



J. Mynde fc.

EXPERIMENT 5.

To the Hole *a* in the Middle of the under Side of the Plate G of the Air-pump, ſcrew on the hollow Braſs Cylinder B. This Cylinder coheres with the Glaſs Tube T, open at both Ends, whoſe lower End is immerg'd in Mercury, contained in the Box P. The Mercury is ſuſtained in the *Torricellian* Tube *ig*, as was ſaid before *. The Veſſel V, together with the Tube, is put upon the Plate G, and covered with the Glaſs Receiver R. The Receiver is open at Top, and has the Braſs Cover E, to which the Cylinder C is join'd, into which is put the End of a wider Glaſs Tube D, which is clos'd at Top, and contains the Tube *ig*. By theſe all Communication between the outward Air and the Veſſel V is taken away. The Air, in the Tube T, only communicates with the Air in the Receiver R and the Tube D, and by it's Elaſticity hinders the Mercury from riſing into the Tube, by the Preſſure of the external Air; the Air alſo, inclos'd in the Receiver R, ſuſtains the Mercury in the Tube *gi* by its Elaſticity *. The Air muſt be drawn out from the Veſſel R; whilſt the Denſity decreaſes, the Elaſticity decreaſes alſo *, and the Force, by which the Mercury is ſuſtained in the Tube *gi*, is leſs; therefore the Mercury deſcends. At the ſame Time the Preſſure of the external Air overcomes the Reſiſtance in the Tube T; and the Mercury aſcends into the Tube. The Diminution of Elaſticity in the Tube T, and Veſſel R, is the ſame, and the Effect of the Diminution in each Caſe is the ſame: Therefore the Mercury deſcends ſo much in the Tube *ig*, as it riſes into the Tube T; which agrees with the Experiment. By this Method the Mercury is raiſed to *f*, whilſt the Tube *gi* remains almoſt empty; the Air being again let in, the Mercury aſcends into the Tube *gi*, whilſt it ſinks in the Tube T.

2173. Pl. 68. F. 1. * 2154. * 2085. * 2115. * 2109.

This Experiment confirms the Rule concerning the Elaſticity of the Air, mentioned before *. The Diminution of the Quantity of Air, in every Motion of the Pump, follows the ſame Ratio; for the Air contained in the ſame Receiver, when the Piſton is applied to the Bottom, is always to the Air, which remains in the Receiver, after the Motion of the Piſton, as the Capacity of the Receiver, and the Part of the Barrel, which the Piſton has left empty, to the Capacity of the Receiver alone.

2174. * 2101.

Whence we infer, that *the Quantities of Air, which remain after each of the ſucceſſive Motions of the Piſtons, are in geometrical Progreſſion; as are alſo the* Denſities *, and the *Elaſticities* †, which laſt is now to be confirm'd.

2175. * 1459. † 2109.

EXPERI-

EXPERIMENT 6.

2176. In this Experiment we make uſe of any Receiver whatever, but
Pl.68.F.1. we muſt have the Tube T: In that which I ſhall now mention the Receiver was not very large.

After two Agitations of the Pump, that is, after one Motion of each Piſton, the Height of the Mercury in the Tube T was 11, 1 Inches; again, after two Agitations the Height was 17, 85 Inches: Laſtly, in two Agitations more it came to the Height of 22, 1 Inches.

The Height in the empty Tube was 29 Inches.

2177. Therefore the compreſſing Forces, which are equal to the De-
* 2100. grees of Elaſticity, were 29; 17, 9; 11, 15; 6, 9 *; which Numbers differ little from a geometrical Progreſſion: For if we ſeek two mean Proportionals between the firſt and the fourth, we have this Proportion, 29; 17, 97; 11, 14; 6, 9.

2178. In the fifth Experiment we ſaid, that the Tube, enclos'd in the Receiver, was almoſt emptied of the Air; for if there ſhould be no Air at all in the upper Part of the Tube, the Air can never be ſo taken out from the Receiver, as that there will be the ſame Height of Mercury in the Veſſel and in the Tube; if this obtains, as ſometimes happens to thoſe, who are leſs careful, we may be certain, that there is ſome Air in the Tube.

2179. The Mercury which remains in the Tube, ſhews that there remains a Preſſure upon the Surface of the Mercury in the Veſſel.

2180. We have ſeen that all the Air can never be taken out of a Veſſel, by repeating the Strokes of the Pump; but yet that it can be ſo
* 2136. diminiſhed, that the Denſity will not be ſenſible *. But if we conſider the Conſtruction of Pumps, this is manifeſt enough; that, when the Piſton is applied to the Bottom, all the Air can never be ſo thrown out, ſo that none at all will remain; whence it follows,

2181. that *the Denſity of the Air in the Veſſel, which is emptied, cannot be*
2182. *diminiſhed beyond a certain Degree*; yet, *if* we come to compute it, we find this Denſity ſo ſmall, that *the Elaſticity* wou'd be very little ſenſible, if it *ſhou'd be diminiſhed with the Denſity*. If a ſix hundredth Part of the Air ſhou'd remain, and it appears that there often remains a leſs Part, *the Elaſticity wou'd not ſuſtain the Mercury at the Height of a twentieth Part of an Inch*. But we muſt determine nicely what the Elaſticity is equal to.

2183. This is eaſily obtained, when in Exp. 5. we make uſe of the *Torricellian* Tube well emptied; for then the Height of the Mercury

cury in the Tube, after the Receiver is exhauſted, immediately ſhews the elaſtic Force of the remaining Air; but it is very difficult, before Immerſion, to fill the Tube with Mercury, ſo that no Air at all may remain in it.

We muſt then uſe the Barometer. The *Torricellian* Tube is ſo call'd, when it is applied to a Frame, on which are marked Diviſions at the Side of the Tube, that the Height of the Mercury in the Tube may immediately be known. In the Conſtruction of ſuch an Inſtrument greater Care is taken, than in filling a Tube, which is made uſe of in one or two Experiments. Therefore if we have a Barometer, made by a good Workman, and in which the Diviſions accurately ſhew the Height of the Mercury in the Tube, *the greateſt Height, to which the Mercury can riſe in the Tube T, will be to be ſubſtracted from the known Height of the Barometer, and the Difference will expreſs the Height, at which it can be ſuſtained by the Elaſticity of the Matter, remaining in the Receiver.* 2184. 2185.

But if we have not ſuch a Barometer, we may make uſe of this Method. We may fill with Mercury a ſhort Tube, about three Inches long, and immerge it in Mercury, contain'd in a Veſſel, as was ſaid of the *Torricellian* Tube *; but a ſmall Tube may more eaſily be fill'd nicely; and when it is once prepar'd it is eaſily kept, to ſerve again, as often as you pleaſe; that, which I make uſe of, has been fill'd above twenty Years. Along the Tube on one Side there is applied a Paper, on which is drawn a Line divided into Inches, and ſmaller Parts; I made uſe of Rhinland Inches divided into Twelfths, which are call'd *Lines*. The Tube is faſten'd, that it may be vertical. 2186. * 2085.

Experiment 7.

Theſe Things being thus prepar'd, the ſmall Veſſel V with it's Tube A B, is covered with any Receiver whatever; the Air being exhauſted as much as poſſible, the Height of the Mercury is meaſured by help of the Diviſions join'd to the Tube. 2187. Pl.69.F.1.

This Height is very different according to the different Temper of the Air, and always greater when it is moiſt. In which laſt Caſe the Height is ſometimes ſeven Lines, that is, it exceeds half an Inch; at other times, the Height is leſs than a Quarter of an Inch, but this ſeldom happens. 2188.

When, the Elaſticity of the Air can be no further diminiſhed, by repeating the Strokes of the Pump; which is known, when the Mercury ſinks no more in the ſaid Tube, or when it is no longer rais'd 2189.

in the Gage of the Pump, we muſt not conclude, that the Denſity of the Air cannot be diminiſhed any more.

2190. The Experiment concerning Sound, which we ſhall explain in
* 2324. what follows *, evidently ſhews, that the Denſity is diminiſhed, by continuing the Strokes of the Pump, whilſt the Gage is not al-
2191. ter'd at all; which follows, from a very remarkable Property of *the Matter, which remains in the Receiver*; for this Matter, *although it*
* 2137. *be dilated, keeps it's Elaſticity*; as has been ſhewn above *, and is immediately demonſtrated by Experiment.

Experiment 8.

2192. We make uſe of the ſame Tube A B together with it's ſmall
Pl.69.F.1. Veſſel V, and us'd in the laſt Experiment, and cover it with a leſs Receiver, which may be done. The Receiver is ſo diſpos'd, that it may incloſe the Hole *a* in the Middle of the Plate G. Into this Hole is put the Screw, cohering with the Bottom of the Syringe P, which is join'd to the Plate by Means of it. The Piſton fills the Syringe nicely, ſo that the Air cannot paſs by; but the Air can go freely through the Hole in the Bottom from the Receiver into the Syringe.

2193. The Air being exhauſted, ſo that the Height of the Mercury in A B might be two Inches, I ſtopt the Communication between the Barrels, by which the Air is exhauſted, and the Receiver; but the Piſton of the Syringe P being depreſs'd, the Deſcent of Mercury in the Tube A B was four Lines; that is, it was equal to a ſixth of the whole Height.

Continuing to empty the Receiver, the ſmalleſt Height, to which the Mercury in the Tube cou'd be reduc'd, was ſix Lines: The Communication with the Barrels, by which the Air is taken out, being now ſtopt again, and the Piſton of the Syringe being de-
* 2109. preſs'd, no Alteration at all cou'd be perceiv'd in the Height of the Mercury in the Tube; according to the Rule * the Mercury ſhou'd have been depreſs'd the twelfth of an Inch.

2194. The elaſtic Matter, produced from Water, has this Property alſo, that the Elaſticity is not diminiſhed with the Denſity, as was ſaid in N. 2131.

Experiment 9.

2195. A ſpherical Glaſs Veſſel, which has a long Neck, is inclos'd in a higher Receiver (as the Upper Receiver R in Fig. 2. Plate 71.) and, the Air being exhauſted, it is left for ſome time, that the greater Part of the Matter mentioned may go out of the Water.

The

The Receiver being taken away the Veſſel is inverted, and the Aperture of the Neck is immerged in a Glaſs, containing Water, but which is alſo clear'd in Part of the ſaid Matter. The Veſſel remains full of Water *. This is covered with the Receiver toge- * 2088.
ther with the Glaſs; and the Air is drawn out, 'till the Surface of the Water in the Neck of the Veſſel agrees to the Surface of the Water in the Glaſs. The Elaſticity of the Matter remaining in the Receiver is meaſur'd *. This is equal to the Elaſticity of the Mat- * 2185.
ter, which, during the Evacuation, went out of the Water into 2186.
the Veſſel; for if this Matter ſhou'd not ſo preſs the Surface of the Water in the Neck of the Veſſel, the Water by it's Preſſure upon the external Surface wou'd riſe into the Neck *. * 1416.

The Air being let into the Receiver, the Water riſes into the Veſſel, and the elaſtic Matter is reduc'd into a ſmall Bubble; which if we meaſure, we find the Dilatation of the Matter in the Experiment; by comparing the Magnitude of the Bubble, with the Magnitude of the Veſſel itſelf.

By ſuch an Experiment we often find that ſuch a Bubble is di- 2196.
lated ten thouſand times, or fifteen thouſand times, and more.

But the Elaſticity in theſe Experiments is always ſufficient to ſuſ- 2197.
tain a Column of Mercury, which is not leſs, and frequently greater, than an hundredth Part of that, which is ſuſtained by the Weight of the whole Atmoſphere.

By the following Experiments we ſhall illuſtrate ſome other Phæ- 2198.
nomena, which depend upon the Weight, or Elaſticity of the Air.

Experiment 10.

If the Piſton of a Syringe be applied to it's Bottom, and a 2199.
Tube join'd to the Syringe be immerg'd in Water; the Water, if the Piſton be rais'd up, will follow it, and fill the Cavity between the Bottom of the Syringe and the Piſton.

It is manifeſt that this Aſcent is to be attributed to the Preſſure 2200.
of the outward Air; for this Reaſon, the Water does not riſe into the Syringe in a Vacuum; becauſe this Preſſure is wanting.

Experiment 11.

Join the Glaſs Tube *b c* to the Syringe A, which is faſten'd to 2201.
the Braſs Cover O, with which the Glaſs R to be exhauſted is cover'd, Pl.67.F.4.
the End *c* of which Tube deſcends below the Surface of the Water, contain'd in the Veſſel V; thruſt down the Piſton to the Bottom of the Syringe, and let the Air be pump'd out of the Receiver. If then you pull up the Piſton, the Water will not riſe.

2202. The Force, by which the Air preſſes upon Bodies, often breaks them, when the Preſſure is not equal every Way.

EXPERIMENT 12.

2203. Pl.68.F.2. The Braſs Cylinder, or truncated Cone, A, is cover'd with a flat Piece of Glaſs, and the Ingreſs of the Air is hinder'd by putting Wax round it; if the Air is pump'd out of the Cylinder, the Plate of Glaſs will be broken by the Preſſure of the external Air, and reduc'd into a kind of Powder, if it be not too thin; if it be too thick it ſuſtains the Preſſure without breaking.

2204. Though the Air preſſes downwards, yet ſometimes ſome Parts of the Glaſs are thrown ſide-wiſe with great Force, ſo as to endanger the Eyes of thoſe that ſtand by; therefore we cover the Cylinder A with the Receiver R. And that the ſmaller Pieces of Glaſs may be taken away, and that no Piece may get into the Pump, I cover the Plate G of the Pump with Paper. The Paper has a Hole in it in the Place, that anſwers to the Hole, through which the Air goes out; ſo that the Paper does not hinder the Braſs ſolid Piece B, whoſe Screw D anſwers to the Screw in the ſaid Hole, from being join'd to the Plate G. To the ſame Solid, by Means of the Screw C, is join'd the ſmaller Braſs Plate O, of the ſame Kind as thoſe that cover the Glaſſes, as in Fig. 4. of this Plate. The ſolid Piece B has a Hole in it, and into the upper Part of the Hole is put the ſmall Pipe E, which is bent at *i*. With a Leather, prepar'd, as was ſaid
* 2156. of the Rings *, we cover the Plate O, and put the Cylinder A upon it; ſo that this Plate receives no Damage at all.

2205. If the Glaſs ſuſtains the whole Weight of the Atmoſphere, you muſt give it a gentle Blow; for this Reaſon we make Uſe of a Receiver open at Top, as R.

EXPERIMENT 13.

2206. Pl.68.F.3. Take a Syringe A of the Diameter of three Quarters of an Inch; puſh down the Piſton to the Bottom of it, and ſtop the Hole at the Bottom of the Syringe; if the Weights P, *p*, which together are equal to five Pounds, be join'd to the Syringe, and the Handle B of the Piſton be held in the Hand, the Syringe will not deſcend, although it be ſuſtain'd itſelf, together with the Weights; for it cannot deſcend, unleſs the Weight hung on it overcomes the Preſſure of the Air, which exceeds ſix Pounds. If inſtead of five we hang on ſix Pounds, the Syringe will deſcend; becauſe to the ſix Pounds there is ſuperadded the Weight of the Syringe. Care muſt be taken that the Friction of the Syringe be very ſmall.

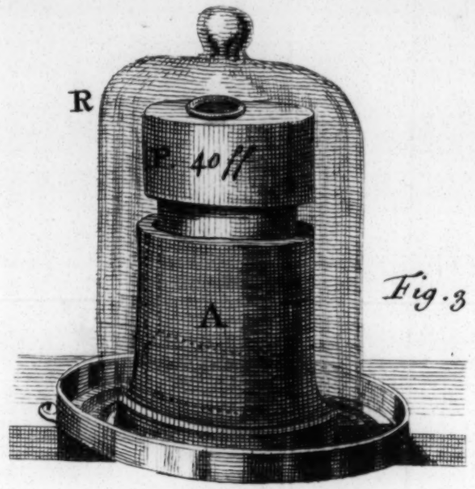


Fig. 3.

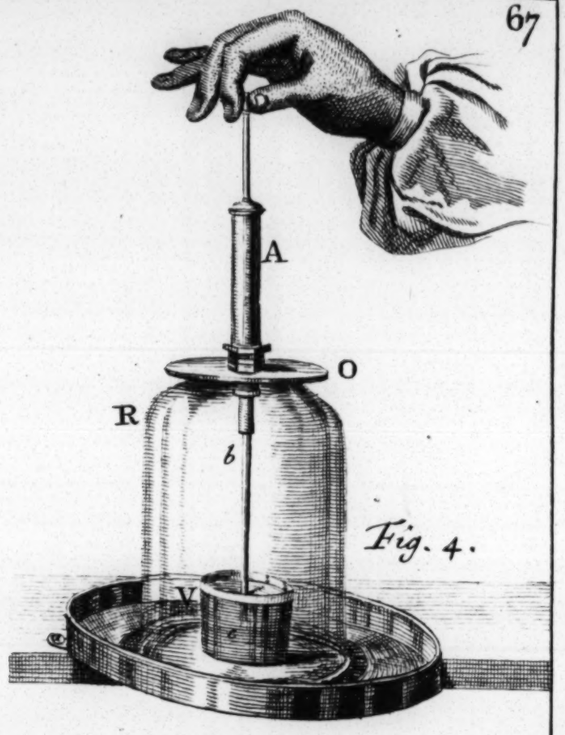


Fig. 4.

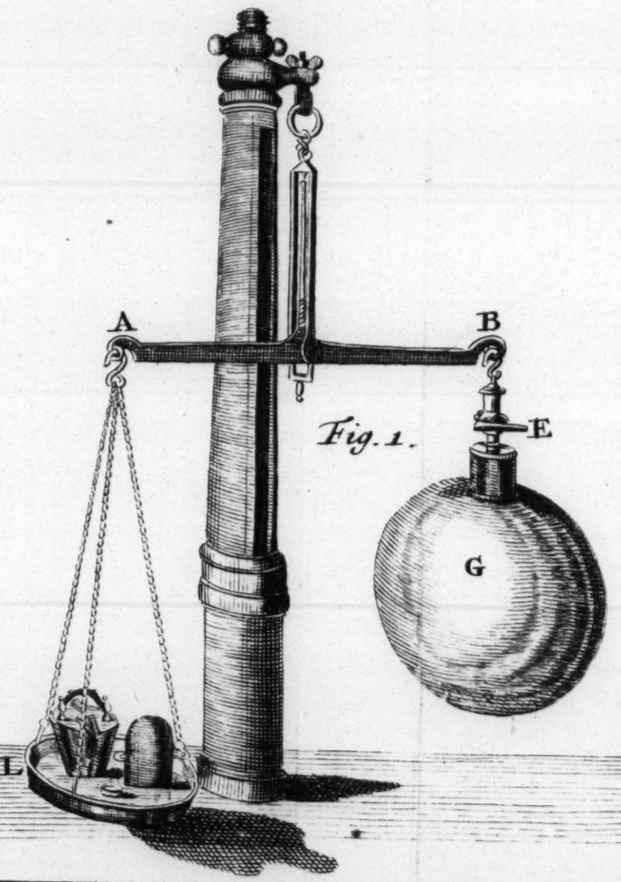


Fig. 1.

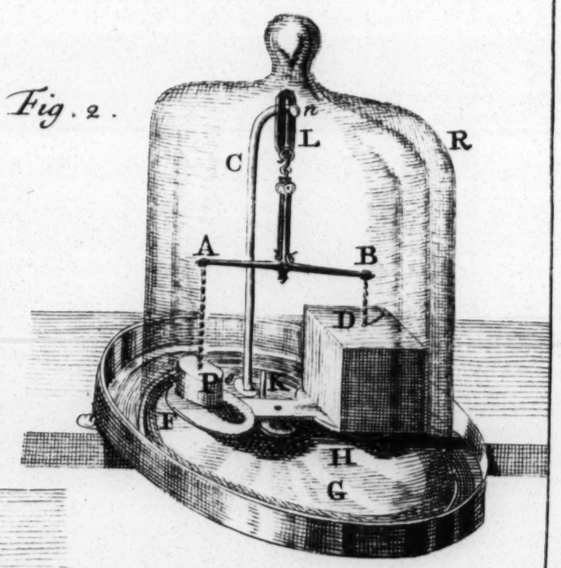


Fig. 2.

J. Mynde sc.

EXPERIMENT 14.

The Syringe deſcends by it's own Weight, in a Vacuum. 2207. Pl.68.F.4.

EXPERIMENT 15.

We ſee a more ſenſible Effect of the Preſſure of the Air, when the two Segments of a Sphere, H and E, are join'd together. Let the Brim or Edge of each of them be well poliſh'd, ſo that they may fit together, and, when they are applied cloſe, put a little Wax between, to exclude the Air. There is a Cock in the Segment H, by which the two Segments, when joined together, may be applied to the Air-pump *, and which muſt be ſhut, when you have exhauſted the Air. The Segments are ſuſpended by the Ring A, and, by the Ring Q, you may hang to them the Weights that are laid upon the great wooden Scale T. If the Diameter of the Segments be three Inches and an half, a Weight of about 140 Pounds will be requir'd to pull them aſunder. 2208. Pl.69.F.2. * 2153.

We make Uſe of the Machine with three Legs beforemention'd *, and apply the Ring A to the Hook V, which can be rais'd and let down, that the Scale T may be ſuſpended at a ſmall Diſtance from the Ground. The Ring Q is put into the Hook G, which coheres with V by a ſmall String, that the Segment E may not fall down, and receive Damage. 2209. * 1441.

The Scale T together with its Chains weighs fifteen Pounds, we put on an hundred and twenty five Pounds, and the Segments are ſeparated, if the Height of the Barometer be leſs than twenty nine Inches; ſome Weight muſt be added, when the Preſſure of the Atmoſphere is greater. 2210.

If theſe Segments are hung up in a Vacuum, they will be ſeparated by ſo ſmall a Force, as is requir'd to overcome the Coheſion of the Wax. 2211.

EXPERIMENT 16.

On the Plate G, of the Air-pump, is put the Wooden Ring B B, which is ſupported by three Feet; the braſs, bent Plate D ſtands upon it, which makes a kind of Handle, and is faſten'd by Screws, one of which is ſeen at *i*. In the upper Part of the Handle there is faſten'd the Hook V, on which are hung the Segments H and E, join'd together, and exhauſted, as in the laſt Experiment. 2212. Pl.69.F.3.

Then a Collar of Leathers is join'd, at Bottom, to the Plate G *. The Braſs Wire F C paſſes through it; whoſe End C with the Ring * 2213. 2155.

of the Segment E is join'd to a Hook made of a ſmall Braſs Wire, as is repreſented at N, in Figure 4.

2214. All theſe Things are inclos'd in the Receiver R, and the Air is exhauſted; and the Segments are very eaſily ſeparated, by pulling the Handle M downwards.

The Ring B B hinders the lower Segment, when it falls, from breaking the Glaſs R, or damaging the Plate G.

2215. A Force, equal to that, which was applied in the laſt Experiment but one, is requir'd to ſeparate the Segments mentioned, when they are inclos'd in a Veſſel, and Air being left between the Segments of the ſame Tenor as the external Air, and the Cock being ſhut, the Air in the Veſſel is brought to a double Denſity.

A MACHINE,

Whereby Experiments are made in condens'd Air.

2216. This Machine is of Braſs, and conſiſts of the Hollow Cylinder
Pl.70.F.1. M N, whoſe Diameter is ſix Inches, and Height eight, or ten Inches. It's Baſes are made of thick Metal; to theſe are join'd the Rings *b* and *d*, which ſurround the Cylinder, that the Machine may the better reſiſt the inward Preſſure; for the ſame Reaſon the Ring *c* is alſo ſolder'd to the Middle of it, with which in the upper Part the Cock B coheres, and at Bottom the perforated Piece (*s Fig.* 4.), that by Means of a Screw the Collar of Leathers may be
* 2155. join'd to the Machine *. When we don't uſe the Collar of Leathers, we cloſe the Hole with a plain Stop.

2217. The fore-part of it, which is repreſented ſeparately at C, has a
Pl.70.F.2. Hole, whoſe Diameter is four Inches. This Hole is ſurrounded by the Prominence *o o*, and at a ſmall Diſtance from it the four Screws *i*, *i*, *i*, *i*, go into the Baſe.

2218. This Hole is clos'd by a Cover, whoſe Inſide is repreſented at D; and it's Outſide is ſeen at Fig. 1.

To the Inſide of this Cover, which has a Hole in it, the Glaſs Plane X is applied, whoſe Diameter is three Inches and an half, and which is more than a third of an Inch thick. The Diameter of the Hole, ſtopt by this Glaſs, is leſs than three Inches. The Cover is made hollow, to receive the Glaſs; but by Reaſon of the Thickneſs of the Glaſs, the Metal muſt be pretty thick round it, and the Glaſs is encompaſs'd with a Kind of Ring, that it may be faſten'd with Cement.

In

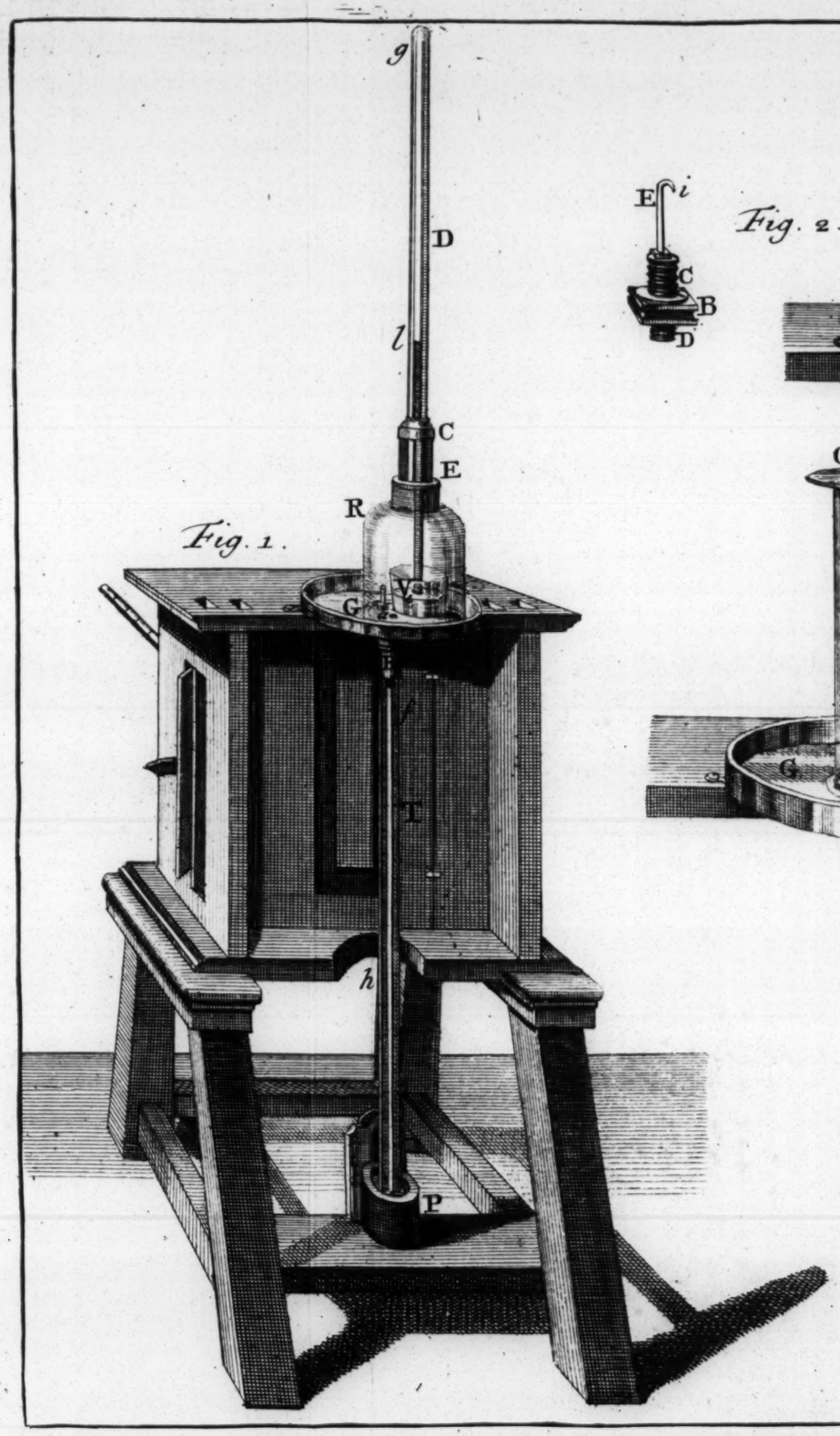
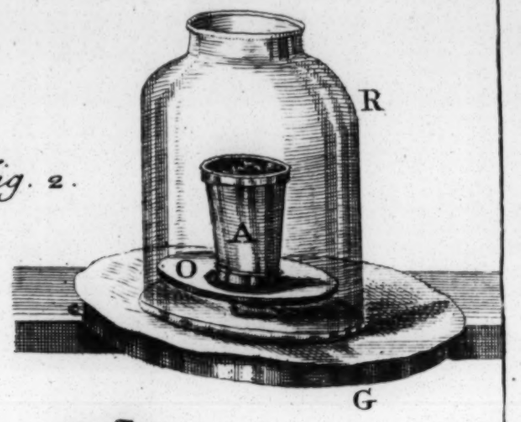


Fig. 1.

Fig. 2.



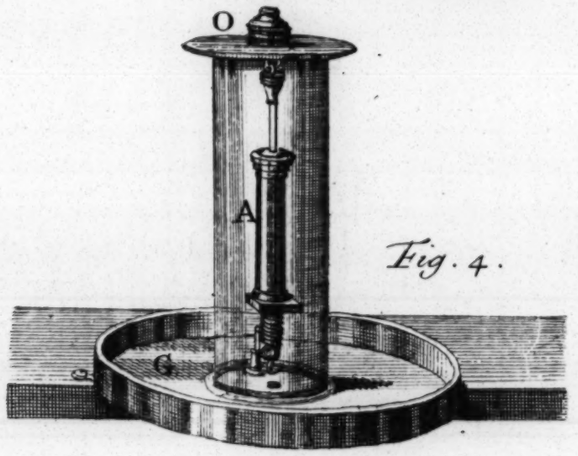


Fig. 4.

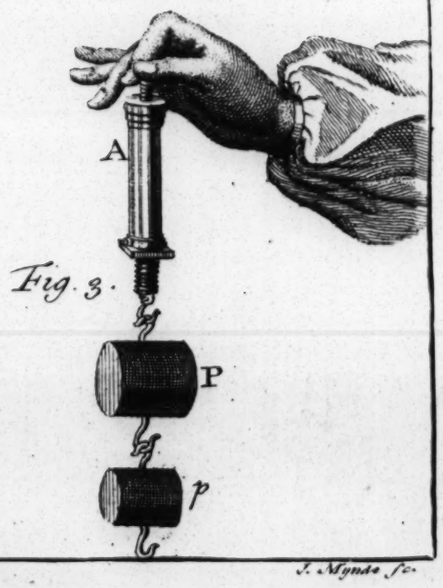


Fig. 3.

J. Nynds Sc.

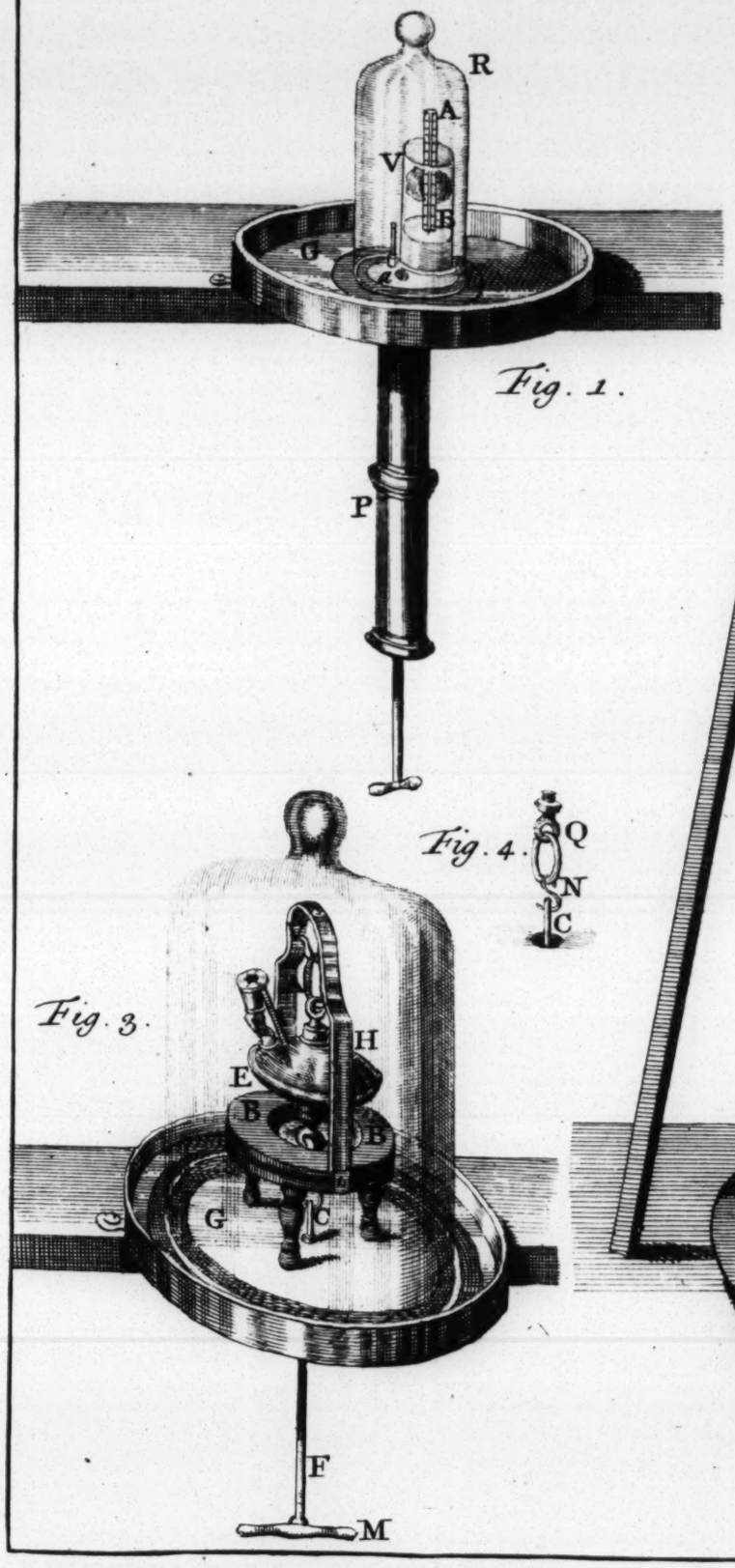


Fig. 1.

Fig. 2.

Fig. 3.

Fig. 4.

J. Mynde sc.

In the oppoſite Baſe, there is a like Hole, which is clos'd in the Inſide, in the ſame Manner, by a like Glaſs Plane.

The Hole C is clos'd by the Cover D, as was ſaid, which that it may be done exactly, the Ring, ſurrounding the Glaſs, is encompaſs'd with the Groove *n n*. Into this Groove is put a Ring of Leather, which covers the Bottom of the Groove, and is of the ſame Breadth. The ſame Thing muſt be obſerv'd with reſpect to this Leather, as was upon another Occaſion *. 2219. * 1436.

When the Cover is applied to the Hole C, the four Screws *i*, *i*, *i*, *i*, go through as many Holes in the Cover itſelf, and the Ring *o o* goes into the Groove *n n*, and compreſſes the Leather in the Bottom of it; the external Screws (*e*, *e*, *e*, *e*, *Fig.* 1.) are join'd to the Screws *i*, *i*, *i*, *i*, and the Cover, by Means of them, is well faſten'd on; but the Ring *o o* ſtands out in ſuch Manner, that it alone immediately touches the Cover; ſo that the Leather ſuſtains the whole Compreſſion.

This Machine is join'd to the wooden Stand F F, which is put upon another Stand G alſo, from which it is eaſily remov'd. 2220. Pl.70.F.1.

When the Air is to be compreſs'd, we make uſe of the Syringe A, from which the Bottom B may be ſeparated. The Piſton E fills it's Cavity exactly; the Leathers *i i*, are ſo diſpos'd, that the Piſton muſt be thruſt in through the Hole *p*, the Bottom being taken away; the ſame muſt be obſerv'd of theſe Leathers as was ſaid above *. Whilſt the Piſton is thruſt in, it's Tail D is put through the Hole in the Cover C, which is applied to the Syringe; that this may be done the Handle M is ſeparated from it, which is again join'd to it, and retain'd by the Screw *n*. 2221. Pl.71.F.1. * 2141.

After the Piſton is thruſt in the Bottom B is added to the Syringe, and a Leather Ring * being put between, it is well faſten'd by the help of Keys, one of which is join'd to the Cover, and the other to the Syringe itſelf at *f*. * 1438.

At *t* there is applied a ſmall Leather Valve, that the Air may go out of the Syringe, through the Hole in it's Bottom, but not get into it: For this Reaſon, when the Piſton is remov'd from the Bottom, the Syringe remains empty, 'till the Piſton comes to the Top; but then the Air enters through the Hole *o*. When a Syringe is us'd, whoſe Bottom can't be taken off, there is a peculiar Method of thruſting in the Piſton; I generally prefer the Syringes whoſe Bottoms may be remov'd, excepting ſuch as are us'd in Air-Pumps. 2222.

The Syringe is join'd to the Cock B, of the Cylinder M N, the mercurial Gage K being put between. This conſiſts of a Glaſs Tube 2223. Pl.70.F.1.

of a very ſmall Bore, and contains a ſmall Quantity of Mercury, which Compreſſes the Air in the hinder Part of the Tube, as much as that, in the Machine itſelf, is compreſs'd. But the Degree of Compreſſion in this Tube is eaſily meaſur'd.

2224. The Machine is now to be taken from it's Stand G, the Cock B being open'd. The Perſon, who undertakes to compreſs the Air, ſets his Feet upon the Boards F, F; and raiſes, and depreſſes the Piſton, and, by continuing this Motion, compreſſes the Air in the Veſſel as much as he pleaſes; then the Cock B is ſhut. The Experiment being ended the Air muſt be let out through the Cock, before the Screws, which keep on the Cover, are looſen'd.

Experiment 17.

2225. Join together the Segments H and E *; and ſuſpend them in the
Pl. 70. Cylinder MN, by help of the ſolid Piece P, which is fixed in the
F. 3. 4. upper Part of the Cylinder, by help of the Screw *p*, which goes
* 2208. into the lower Part of the Cock B; this Piece has a Hole in it, that the Air may go through the Cock, into the Cylinder.

* 2216. The Collar of Leathers I is join'd at *s* to the Machine *. The Braſs Wire, which goes through this Collar, muſt be thicker, than in the other Experiments.

To the End of this Wire, which goes into the Cylinder, is join'd the Piece R, into which this End, which has a Screw, is put. This Piece is eaſily join'd to the Segment H, as the Figure ſhews.

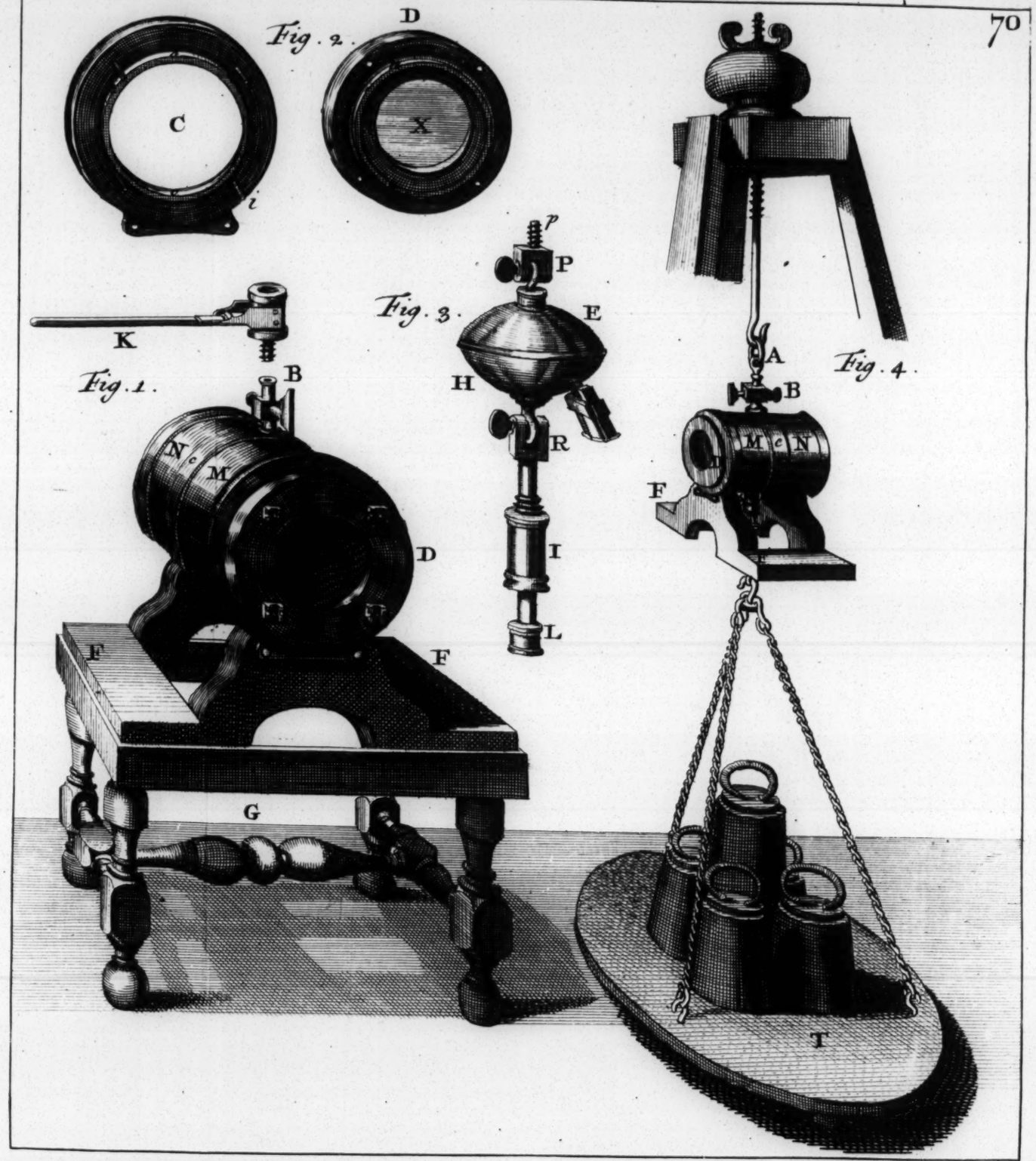
The Cock of the Segment H is ſhut, that the Air may not get between the Segments; for which Reaſon Wax is put round it, as in the foregoing Experiments.

2226. Things being thus diſpos'd, the Cover is applied to the Cylinder *,
Pl. 70. F. 4. and the Air is compreſs'd. The Syringe with it's Gage is remov'd †,
* 2219. and, the Ring A being join'd to the Cock B, the Machine is ſuſ-
† 2223. pended by the Hook V, as was ſaid of the Segments above *.

* 2209. To the lower End L (*Fig.* 3.) of the Wire that goes through the Collar of Leathers, there is join'd a Ring alſo, on which the Scale T is ſuſpended.

By putting Weights upon this Scale, the Segments in the Cylinder are ſeparated. If the Denſity of the Air in the Cylinder be double, the Weight will not differ much from that, which was us'd in the laſt Experiment but one; the Weight muſt have been doubled, if the Denſity of the Air had been triple, or if the Segments had been exhauſted.

But



J. Mynde fc.

But Care muſt be taken, 1. That the Screw D C be ſo diſpos'd, that the Scale T may deſcend but a little before it be put upon the Ground; otherwiſe the ſolid R (*Fig.* 3.) would run againſt the inner Surface of the Cylinder with too great a Force. 2. That two Sponges are plac'd, ſo as to receive the Segment H, that it may not be damag'd. 2227.

EXPERIMENT 18.

Apply the Pipe A B to the Plate G of the Air-pump, which Pipe has a Cock at it's lower End, and to which is join'd, at Top, the ſmaller Pipe C, which riſes above the Plate. The Pipe D is applied to the Hole through which the Air is taken out. The Glaſs Receiver S is put upon the Plate G, in ſuch Manner, that the Pipe C may anſwer to the Middle of it. Upon the Receiver S is put the Receiver R, that we may have an Height of about three Feet. The End A, of the Pipe A B, is immerg'd in Water, contain'd in the Veſſel V, and the Receivers R and S being exhauſted, the Cock is open'd; the Water will ſpout up into the Receiver with a great Force; namely by that Preſſure, with which it can be ſuſtain'd in a Pipe that has no Air in it, at the Height of thirty two Feet *. 2228. Pl. 71. F. 2. * 1089.

EXPERIMENT 19.

The Air's Elaſticity produces the ſame Effect. Let there be a Braſs Cylinder V, exactly clos'd. There muſt be a Hole in the Bottom to pour in Water, which afterwards you ſhut up with a Screw. To the upper Part of the Veſſel there is ſolder'd a Pipe, which goes down almoſt to the Bottom; and to the other End of it, that ſtands above the Veſſel, the Cock E is join'd. By help of a Screw this Veſſel is fitted to the lower Side of the Plate G of the Air-pump; there is alſo here a prominent Pipe C, which is cover'd with the Receivers, as in the foregoing Experiment. If the Air be exhauſted from them, and the Veſſel V is about two Thirds full of Water, when you open the Cock, the Water will violently ſpout up into the Receivers, by the Force of the Spring of the Air contain'd in the upper Part of the Veſſel V. Here the Air preſſes upon the Surface of the Water; when you open the Cock, the Preſſure in the Pipe becomes leſs, therefore the Water muſt go into the Pipe. 2229. Pl. 71 F. 3.

EXPERIMENT 20.

Even in the open Air, the Water will violently ſpout out of the Veſſel V, if, having pour'd in Water, as in the 17th Experiment, the Air be forc'd into the Veſſel, by the Syringe above-mention'd *. 2230. Pl. 71 F. 4. * 2221.

EXPE-

Experiment 21.

2231. If a Glaſs inverted be immerg'd in Water, the Air keeps out the Water, at whatever Depth it be immerg'd; yet the deeper the Glaſs is put down, the leſs Space the Air is reduc'd into.

2232. Upon this Principle are made the Machines in which Divers go down into the Sea. They are made like Bells, and deſcend by their own Gravity; the Water does not riſe up to the Diver in the Bell; freſh Air is ſent down continually by the Bladders tied to a Rope, which he draws down to him; the Air, heated by his Reſpiration, riſes to the upper Part of the Bell, and is there driven out through a Cock, by the Preſſure of the Water, that puſhes up, and compreſſes the Air in the lower Part of the Bell; which Preſſure overcomes the Force with which the Water endeavours to deſcend through the Cock; for the Preſſure of Fluids is encreas'd in Proportion to their Depths *. * 1468.

Experiment 22.

2233. Take little Figures of Glaſs that are made hollow, of an Inch and half long, repreſenting Men; theſe little Images have a ſmall Hole in one of their Feet, and are lighter than Water. Immerge them into the Water contain'd in the Glaſs AB. This Glaſs is about a Foot, or 15 Inches high. This is put upon the Plate G of the Air-pump, and cover'd with the Receiver R. A Part of the Air being exhauſted, it goes out of the little Images alſo, whoſe Place is immediately taken up by the Water, when the Air is let into the Receiver again; the Images are now heavier, and go to the Bottom. Some of the Air being again exhauſted, the Preſſure upon the Surface of the Water is diminiſhed, and the Air in the Images expands itſelf, and drives out the Water, and the Images riſe up again, and have ſeveral Motions, when the Pump is mov'd. Pl 72. F. 1.

Experiment 23.

2234. We may make Uſe of this Glaſs Veſſel with the Figures in it, in another Manner, without the Air-pump. It is fill'd with Water, and cover'd with a Bladder, which is tied faſt to the upper Part of the Veſſel. If the Bladder be preſs'd with the Finger, the Surface of the Water is compreſs'd more; and this, being more compreſs'd, enters into the Images through the Holes in their Feet, and compreſſes the Air more in them. The Images being made heavier, go to the Bottom of the Veſſel, faſter or ſlower according to the Bigneſs

Fig. 2.

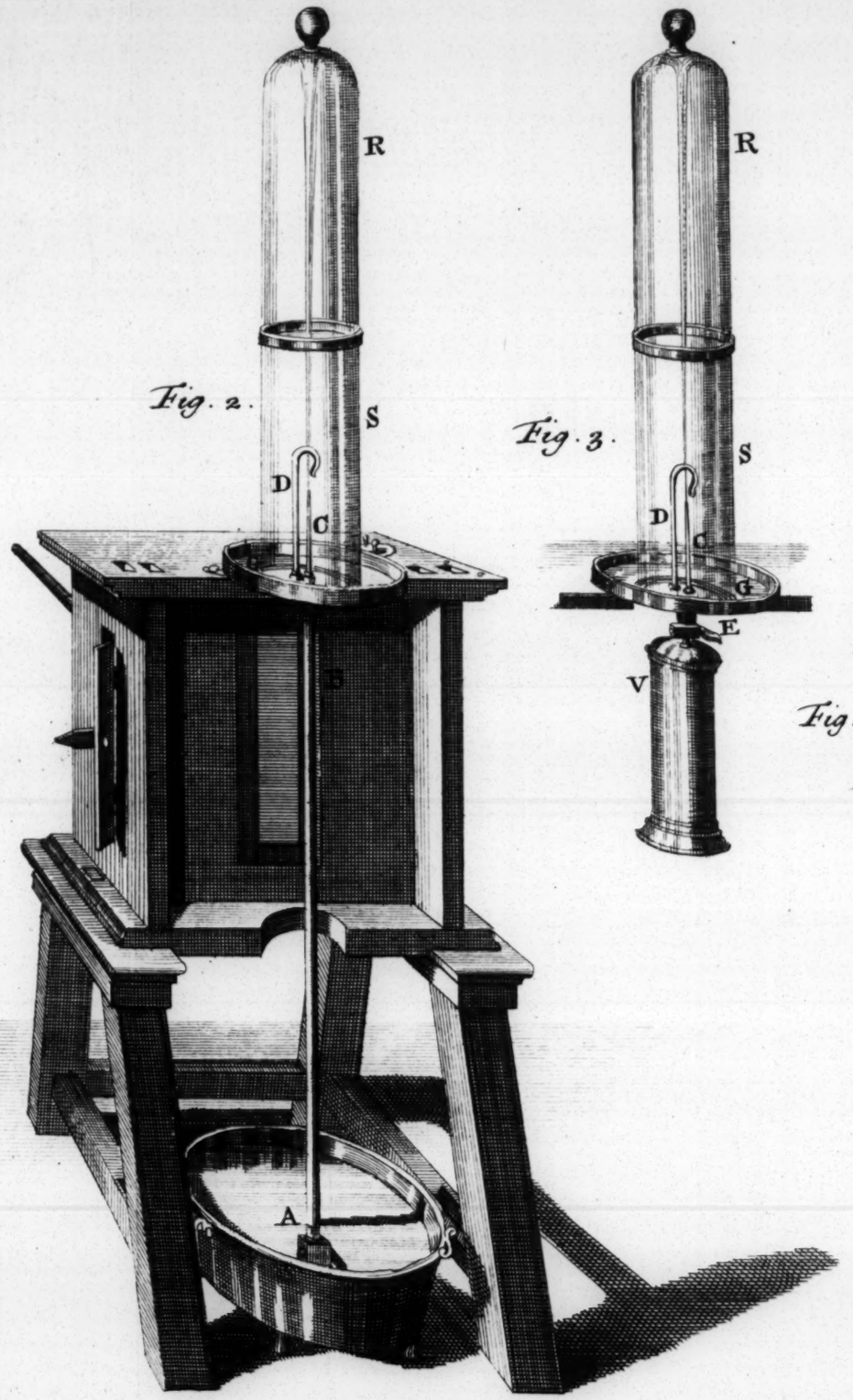


Fig. 3.

Fig. 1.



J. Myndes sc.

Bigneſs of the Hole, and alſo according as the ſpecific Gravity of the Images comes nearer to the ſpecific Gravity of the Water. Taking away your Finger, the Air in the little Men, being leſs compreſs'd, expands itſelf, and drives out the Water, and the Images riſe up again to the Surface of the Water, as in the laſt Experiment.

Experiment 24.

Animals cannot live without Air. If any Animal be included in the Receiver V, and the Air be drawn out, the Animal will immediately be in Convulſions, and will fall down dead, unleſs the Air be ſuddenly re-admitted. Some Animals will live in a Vacuum longer than others. The Bodies of the Animals are ſwoln, whilſt, the external Preſſure being taken away, the Air, or ſome elaſtic Fluid, expands itſelf in the Veſſels. 2235. Pl. 72. F. 2.

Experiment 25.

Some Fiſhes alſo cannot live without Air; but in others you ſee no ſuch Change, but the ſwelling of their Eyes. What Experiments you make upon Fiſhes, muſt be made in the Glaſs Receiver V, which is ſet upon the Plate of the Air-pump, and which contains the Water with the Fiſhes. This is covered with the Receiver R, and the Air is exchanged. The Preſſure of the Air upon the Surface of the Water being taken away, the Air in the Body of the Fiſh expands itſelf, by which it becomes lighter, and cannot deſcend in the Water. 2236. Pl. 72. F. 3.

Experiment 26.

Experiments are made upon Animals in compreſs'd Air, by Help of the Machine above-deſcrib'd *. In that Caſe Animals do not ſoon die; becauſe the Veſſels in the Body are not broken, by compreſſing the Air; the Animals become rather briſker. Yet if they continue long in that condenſed Air, it is hurtful to them; and in a greater Compreſſion, they will die in a little Time. 2237. * 2216.

Experiment 27.

We may ſee what happens to the Veſſels of an Animal, in compreſſed Air, if we ſuſpend a Bladder blown up, and well clos'd, in the ſaid Machine *. When the Air is compreſs'd, it becomes flaccid; but, when the Cock is opened, it ſuddenly expands itſelf. 2238. * 2216.

EXPERIMENT 28.

2239. From ſeveral Fluids, when they are put under a Glaſs Receiver, and the Air is exhauſted, an elaſtic Fluid is ſeparated. In this Caſe we always obſerve an Ebullition of the Fluid, which is often very violent.

2240. In the eighth Chapter of the firſt Book, I mentioned an Expe-
* 153. riment concerning Bodies falling in a Vacuum *, I ſhall now explain it.

A MACHINE,

Whereby two Bodies are let down in Vacuo, at the ſame Time.

2241. This Machine is joined to the Cover of the Receiver. The up-
Plate 73. per Surface of this Cover is ſeen at Fig. 1. the lower Surface at
Fig. 1, 2. Fig. 2. The Machine itſelf, is repreſented ſeparate from the Cover, in the other Figures.

2242. The Braſs Plate A is hexagonical, the Angles being cut off, and
Fig. 3. it is perforated in ſeveral Places, to make it lighter. The Axis *a e* is perpendicular to it, behind it, whoſe Part *a b* is cylindrical, and the Part *be* ſquare, but the End *e* makes a Screw, which the Nut *c* fits.

2243. To the ſame Plate, which is repreſented at B, at the fore Part
Fig. 4. of it, are applied ſix ſmall Braſs Plates E, E, E, E, E, E; which are bent, and elaſtic. One of theſe Springs is repreſented ſeparately at C D; towards C there are two ſmall Holes, through which the Screws *n*, *n* go, that the Spring may be faſtened in it's Place. The End D agrees to a Side of the Hexagon, and preſſes the Plate B by it's Elaſticity.

2244. The Spring C D is perforated at *o o*; and through this Inciſion paſſes the ſmall Plate *i*, which coheres with the Plate B, and turns upon a Center. Every Spring has ſuch a ſmall Plate, which is ſeen
Fig. 5. more diſtinctly in Fig. 5. A B repreſents a Section through the Center of the hexagonical Plate, in ſuch a Poſition, that this Section, which we ſuppoſe vertical, paſſes through the Inciſions of the two Springs E and E. The Plates, of which we are ſpeaking, are repreſented at *i*, *i*; a Piece *p* paſſes through each of them, which is prominent on both Sides.

2245. The Plate of the lower Spring acquires an horizontal Poſition by it's Gravity; becauſe the Piece *p* is ſuſtained by the Spring itſelf. If, when the Plate is in this Poſition, it be preſſed downwards,

wards, the End D of the Spring is ſeparated from the Plate A B by the Action of this Piece.

Upon the ſquare Part of the Axis above-mentioned of the Plate A B *, is put the ſmall Wheel R, which has Teeth, and which is repreſented ſideways at *r*; the Teeth of it are oblique, that they may anſwer to the Screw which we ſhall ſpeak of preſently. We have a Section of this little Wheel, joined to the Axis, and faſtened by the Screw *e c*, at *r*. 2246. * 2242.

That this Machine may be faſtened to the Cover, there is a Cylinder H N, which is joined to the Bottom of it, and which ends in the ſpherical Head I, two Segments at oppoſite Parts being cut off; this Head is perforated at *s*; through which Aperture is put the Axis *a b* (*Fig.* 3, 5.) before the Wheel *r* is joined to it, and faſtened. 2247. Fig. 2.

To the ſame Cylinder H I, is added the Screw G, which is retained between the Plates L and M; the Part *g* paſſes through the Hole *f*, and *h l* through the Hole *d*. The Spiral of this Screw agrees to the Teeth of the Wheel, ſo that, by turning the Screw about it's Axis, the Wheel is mov'd, and the Plate A B *(Fig.* 5.) with what is joined to it is turned round. 2248.

The ſmall Pipe X goes through the Cover, and is ſolder'd to it, to which the Screw G ſo anſwers, when it is fix'd in it's Place, that it's Axis, if it be conceived to be continued, coincides with the Axis of the Pipe.

The Part P of the Key F P fills this Pipe, and indeed ſo exactly, that the Air cannot paſs by, whilſt the Key is turned round, which ſhou'd be anointed well with Oil and Wax. 2249.

This has a Roller in it's lower Part at *m*, which Hole is ſquare, into which goes the Part *l* of the Screw, which is alſo ſquare, and fits the Cavity.

All the Parts are repreſented join'd together in Fig. 1. beſides thoſe, which we have hitherto explained, there is a Collar of Leathers *, which is put upon the Cover, and ſolder'd to it, through which the Braſs Wire S T paſſes, to whoſe End is joined the Plate V at right Angles to it. 2250. Fig. 1. * 2155.

To know where this Collar of Leathers muſt be fix'd, turn the Key F till you bring the lower Side of the Hexagon A into an horizontal Poſition; then the ſmall Plate *i*, which goes through the lower Spring E, will be horizontal alſo *; the Plate V ſhou'd now anſwer to *i*, ſo that, by puſhing down the Wire S T a little, the Spring may be ſeparated from the Plate A, as was before explain'd *. * 2245. 2251. * 2245.

EXPERIMENT.

2252. Pl.72.F.4. That this Experiment may be the more conveniently made, the Air-pump is taken off from it's Stand, and is laid upon the low Stand S S.

At the Sides of the Plate G, upon which the Glaſſes, which are exhauſted, are laid, are faſtened two wooden Pillars A E, A E, the Feet of which go through the upper Board of the Air-pump, and are faſtened by Wedges, as *t*.

The Pillars are above five Feet high; theſe are join'd by four Pieces of Wood, B B, C C, D D, E E. The Diſtance between G and B B is nine, or ten Inches; B C, C D, D E, are each equal to 18 Inches.

Theſe Pieces of Wood are broader in the Middle, that there may be an Aperture, or round Hole in each, whoſe Diameter is equal to five Inches and an half.

Four Glaſs Cylinders F, F, F, F, are made uſe of; the inward Diameter of each is four Inches, and the Height a Foot and an half. The upper Hole of every one of them is encompaſs'd with a round Piece, with which coheres an horizontal Ring made of a Plate of the ſame Metal, that, when Leather is put between *, one Glaſs may be ſet upon another. Theſe four Cylinders are put one upon another, and make, as it were, one hollow Glaſs Column, which paſſes through the Holes in the Pieces of Wood. This Column muſt be ſo plac'd, that it may go through the Middle of all the Holes, as near as poſſible; to effect which the Poſition of the whole Column muſt frequently be altered a little; for this Reaſon the loweſt Cylinder is laid upon the Plate G, without putting a Leather between; but, after the Cylinders are fix'd, the Air is hinder'd from getting between the Plate and the Brim of the Cylinder, by putting Wax round it *. The Cylinders are faſtened by Means of the little Wedges *x*, *x*, *x*, &c. made in ſuch Manner, that they may ſuit the Glaſs and the Hole.

* 2157.

* 2156.

The Glaſs Receiver R is laid upon the uppermoſt Cylinder; the Bottom of it is cylindrical, and this Part of it anſwers to the Cylinders mention'd. The Diameter of the Receiver in the Middle is about ſeven Inches; and the upper Hole is of five Inches Diameter. This Aperture is clos'd with the Cover above-mention'd *, Leather being put between *, and the Machine, there explain'd, is then incloſ'd in the Receiver; but the Bodies, to be let down in Vacuo, muſt firſt be join'd to the Machine.

* 2241, * 2157.

To

To do this, we put a Piece of Gold Coin *p* together with a ſmall Feather *q* between a Spring, as E, and the Plate B; both which Bodies are retain'd by the Preſſure of the Spring, if the Tail of the Feather is of the ſame Thickneſs as the Money; wherefore, that we may make uſe of a lighter Feather, we muſt chooſe a thin Piece of Money (for Example, *a Ducat.*) Each of the Springs ſhou'd retain Bodies like theſe, in the ſame Manner. 2253. Pl.73.F.4.

The Air is exhauſted from all theſe Glaſſes, and by thruſting down the Braſs Wire *st* a little, the lower Part of the lower Spring is ſeparated from the Plate, to which all the Springs are applied *, and both the Bodies, which are held by the Spring, are let looſe at the ſame Time; and they come to the Plate G exactly at the ſame Time alſo. 2254. Pl.72.F.4. * 2251.

The Experiment is eaſily repeated; the Key *f* is turned about, that another Spring may come to the lower Place *; and thus it may be repeated ſix Times. If during theſe Repetitions ſome Air be let in, a Difference in the Time of the Fall of the Bodies is perceiv'd, and the Difference is the greater, the more Air is let in. 2255. * 2248.

A Spectator will ſee the Bodies falling, if he be at ſuch a Diſtance, as to perceive all the Glaſſes at one View, if he be at a leſs Diſtance, let him keep his Eyes on the Plate G.

A more ſimple Method of repeating the Experiment, may indeed be us'd; but I think this, which I have made uſe of, the beſt Method of letting looſe the Bodies, at the ſame Time, that they may fall directly down, and ſeparately. But the following Method is very ſimple, if the Bodies are to be let down only once. 2256.

The Receiver R in this Caſe is remov'd, the upper Cylinder alſo may have a ſmaller Aperture. 2257.

This upper Cylinder is clos'd with the Braſs Top O, to this is join'd a Collar of Leathers A *, by Means of the Screw B, which goes through the Cover in ſuch Manner, that the elaſtic, bent Plate D E is join'd to the Cover by Means of it, which Plate is perforated at Top, over which Aperture is ſolder'd the Ring C, into which the Screw B goes. Pl.73.F.6. * 2155.

The extreme Parts *r r* of the Plate, come together by Means of their Elaſticity, the Ends being a little bent.

In this Plate is inclos'd the oval, Braſs Plate F, whoſe ſmaller Diameter may be contained within the Plate D E, without ſeparating the Ends of it.

Within the ſame Plate D E, the Braſs Wire G I goes, which paſſes through the Collar of Leathers A, and therefore alſo through

the Cover O. To the lower End I of which Wire G I the ſaid Plate F is join'd, which may be mov'd by Means of the Handle Q, and turned round, whereby the Ends *r*, *r*, of the Plate D E are ſeparated; becauſe the longer Diameter of the oval H exceeds the Diſtance between the oppoſite Parts of the Plate, when it's Extremes *r*, *r*, are join'd by Means of the Elaſticity; between theſe the Gold and Feather are put, when the Experiment is to be made.

CAHP. VI.

The Deſcription of ſeveral Machines, whoſe Action depends upon the Air, and the Explanation of their Effects.

Experiment 1.

2258. Pl.74.F.1. LET one End *a*, of the Curve Tube *a* S *b* be immerged in Water, whilſt the other End *b* deſcends below the Surface of the Water. If by ſucking, or any other Way, the Air be taken out of this Tube, the Water will run through *b*. This Inſtrument is called a *Syphon*.

2259. This Effect ariſes from the Preſſure of the Air, which drives on the Water in the Syphon, by it's Preſſure upon the Surface of the Water in the Veſſel. The Air does alſo preſs againſt the Water that goes out of the Orifice *b*, and ſuſtains it. Theſe Preſſures are equal, and act contrariwiſe in the upper Part of the Syphon, with a Force equal to the Weight of the Atmoſphere, taking away the Weight of the Pillars of Water which are ſuſtained by the Preſſure. The Pillar of the Water in the Leg S *b*, is longer than the oppoſite Pillar of Water; therefore, the Preſſure of the Air is more diminiſhed on the Side *b* S, and the oppoſite Preſſure overcoming it, the Water flows towards *b*.

Experiment 2.

2260. The Syphon above-mention'd has this Inconveniency, that, if once it ceaſeth to work, the Water will not run again, unleſs the Air be drawn out of the Tube afreſh. This may be corrected by making a Syphon in the Figure *d* R *e*, whoſe Legs are equal, and turn'd up again; for if the Syphon be fill'd with Water, and one Leg be immerſed in it, ſo that the Surface of the Water may be

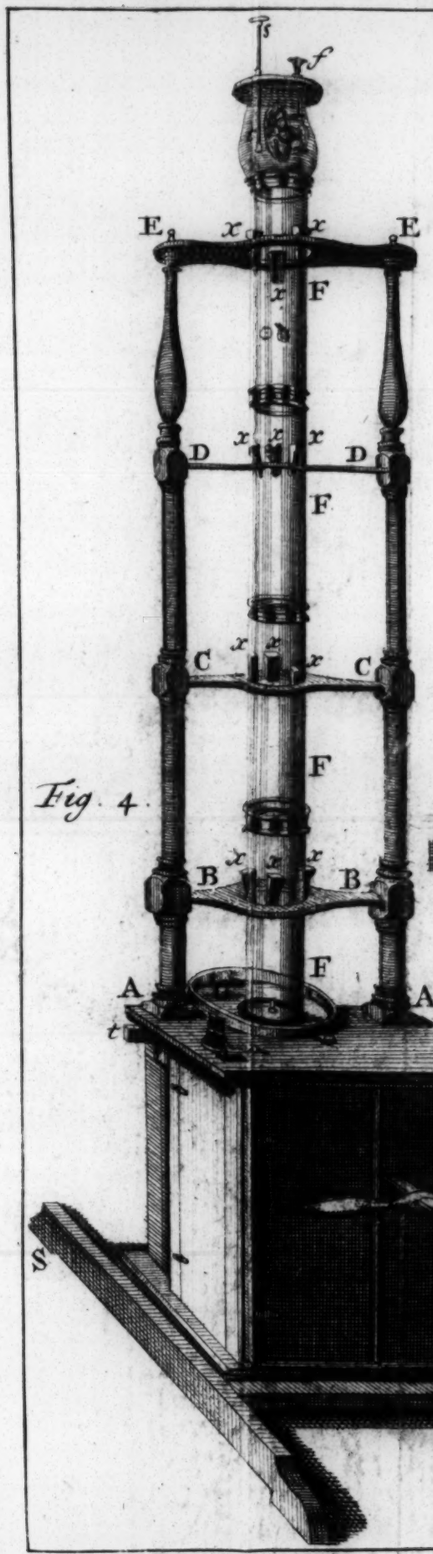


Fig. 4.

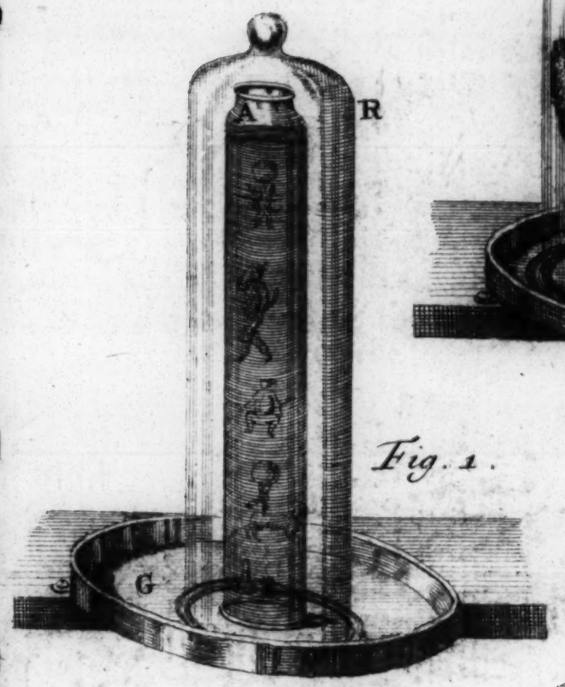


Fig. 1.

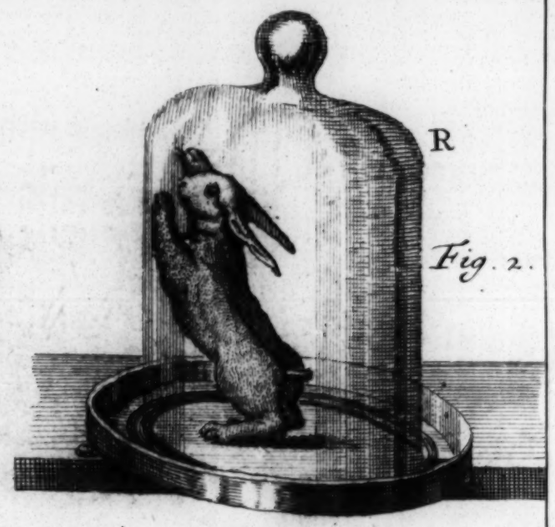


Fig. 2.

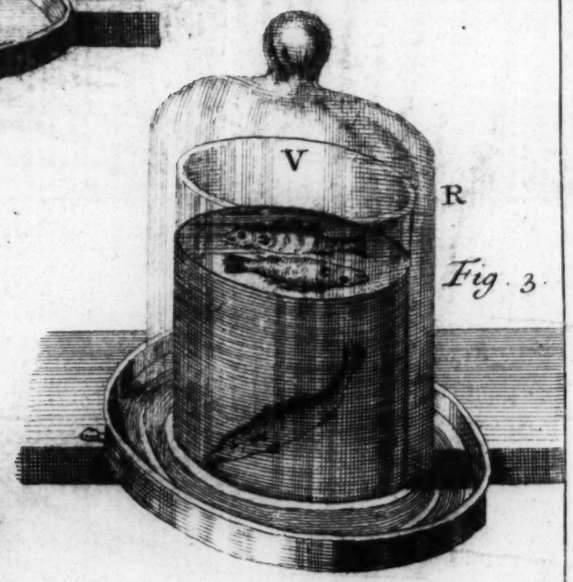


Fig. 3.

J. Mynde fc.

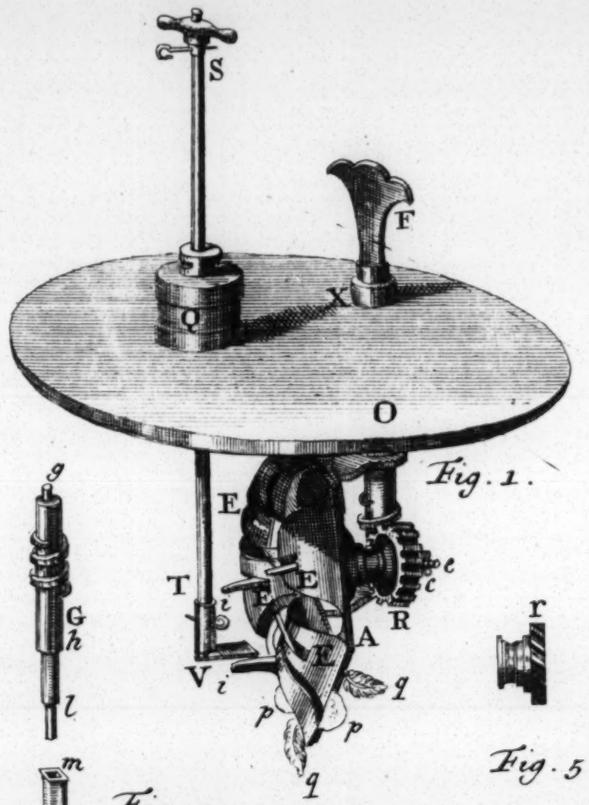


Fig. 1.



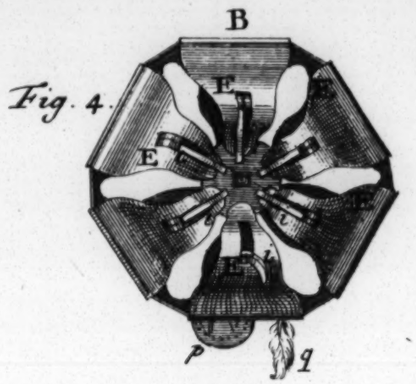


Fig. 4.



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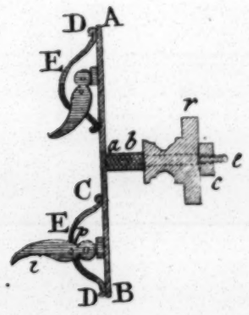


Fig. 5.

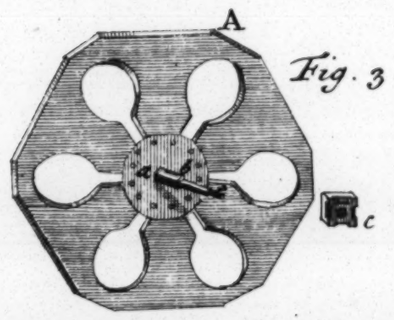
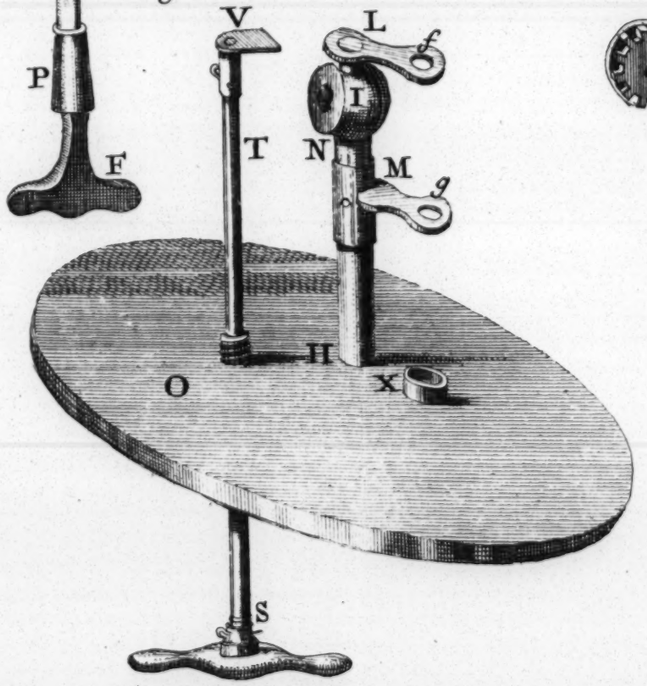
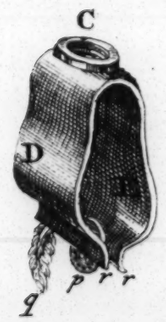


Fig. 3.







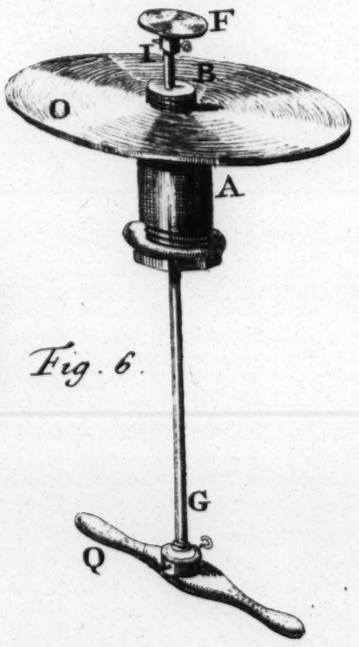


Fig. 6.

J. Meyade fc.

above the Orifice, then the Water will run out through the other Leg, for the Reaſon given in the Explication of the former Experiment. Since the Legs are return'd upwards, the Syphon will not be emptied, when the running out of the Water ceaſes; and ſo the Syphon, being once fill'd, is always ready to work it's Effect. The Water runs backward or forward through it, according as it is higher on one Side or the other.

A SYPHON,
Whereby Water is rais'd.

Upon the ſame Principle as the foregoing Machine, is contriv'd the Syphon for raiſing Water into a Reſervoir. The Effect of this Syphon becomes viſible by the Help of a Machine made up of two hollow Glaſs Balls H and I, which are join'd together by the Braſs Pipe C D E. The Ball I communicates with the Water to be rais'd, contain'd in the Veſſel V, by Means of the Pipe A B, which comes up almoſt to the Top of the Ball; to the Ball H at the lower Part is join'd the Pipe F G, as long as the whole Pipe A B. 2261. Pl. 74. F. 2.

The Ball H muſt be filled with Water through a Hole by a Funnel, and then the Hole muſt be ſhut up cloſe.

In ſuch Machines as are applied to Uſe, for raiſing Water out of a Reſervoir that contains it, the Water is brought away in the Veſſel H, and the Communication between the Veſſel and the Reſervoir is ſhut up with a Cock. 2262.

Experiment 3.

Opening the Cock G, the Water will run out that Way, and will aſcend through the Pipe A B up into the Veſſel I; which being fill'd, the Water is ſuffer'd to run away to the Place where you would have it; and, by repeating the Operation, the Elevation of the Water continues. 2253.

Opening the Cock G, the Water going out of the Pipe F G, ſuſtains the Preſſure of the whole Atmoſphere; the Air alſo preſſes upon the Surface of the Water in the Veſſel V, and it is ſuſtained in the Pipe A B by Means of this Preſſure. Theſe Preſſures are equal, and if you take from them the Columns of Water which they ſuſtain, you will have the Forces by which the Air is preſs'd that is contain'd in the upper Parts of the Veſſels, which communicate by Means of the Pipe C D E. The Pillar F G, becauſe there 2264.

is

is ſuperadded to it the Height of the Water in the Veſſel H, does always overcome the Column in the Pipe A B, therefore the Preſſure at G is more diminiſhed than the other, and ſo overcome by it; and therefore the Water muſt riſe in the Tube A B, and deſcend down F G.

The common PUMPS.

2265. Pl.74.F.3. To render the Action, and Effects of common Pumps viſible, let there be a little Pump made of Glaſs. Let A B be a Cylinder of Glaſs, ſix or ſeven Inches high, whoſe Diameter is an Inch and an half. In the Bottom of it join a Tube of any Length, as C D. Let the upper Part of it be ſtopt up with a Leaden Ball, that the Water may not be able to deſcend out of the Cylinder A B, but may eaſily riſe into it, by raiſing up the Ball, which we make uſe of here inſtead of a Valve. The Piſton is mov'd in the Cylinder A B, which, being ſurrounded with Leather, exactly fills it's Cavity: There is a Hole in the Piſton, which likewiſe is ſtopp'd with a Ball of Lead inſtead of a Valve; ſo that the Water may riſe, but not deſcend through the Piſton.

EXPERIMENT 4.

2266. Puſh down the Piſton to the Bottom; pour Water upon it to hinder the Paſſage of the Air; if the End D of the Tube C D be immers'd into Water, and the Piſton be rais'd, the Water will * 2199. aſcend up into the Cylinder A B *, from which it cannot deſcend; wherefore, it comes up through the Piſton, when it is puſhed down. If you raiſe the Piſton again, the Cylinder is again fill'd with other Water, and the firſt Water is rais'd up into the Wooden Veſſel F, which is join'd to the Glaſs Cylinder, from which it runs out through the Tube G.

2267. Since the Effects of all the Machines, deſcrib'd in this Chapter, depend upon the Preſſure of the Atmoſphere, the Water will not riſe in theſe Machines to an Height of thirty Feet. The Water * 2089. might be rais'd to a greater Height, exceeding thirty two Feet *, * 2129. if, in theſe greater Heights, the elaſtic Fluid, ſpoken of above *, ſhou'd be ſeparated from it.

HERO's *FOUNTAIN.*

2268. There are ſeveral Fountains, which are call'd *Hero*'s Fountains; Plate 69. I ſhall explain the Conſtruction of one of them.
Fig. 4, 5.

The

The two equal elliptical Veſſels A B, and C D, very well clos'd on all Sides, are made of Braſs.

In each there is a Diviſion which goes through the Center of the Ellipſe, and divides it into two equal Parts.

The Diviſion in the Veſſel D C is perpendicular to the Axis of the Ellipſe; that of the other Veſſel is inclin'd to this Axis; the Diſpoſition of the Pipes, which will be mention'd preſently, is the Caſe of this Difference.

The upper Plate E F, of the Veſſel A B, is hollow'd, to contain Water at the Height of an Inch, or two.

The Veſſels are join'd by four Pipes. The firſt *o p* goes through the Cavity B, of the Veſſel A B, and has no Communication with it, and deſcends almoſt to the Bottom of the Cavity D. The ſecond *s t* is ſolder'd to the upper Part of the Cavity D, and reaches to the Top of the Cavity B, without touching the upper Plate. The third *q r* reaches from the lower Part of the Cavity B almoſt to the Bottom of the Cavity C. The fourth *x v* coheres with the upper Part of this Cavity C, and reaches almoſt to the upper Part of the Cavity A.

Laſtly there is a Pipe *y z*, which paſſes through the upper Plate of the Veſſel A B, and is ſo ſolder'd to it, and deſcends into the Cavity A in ſuch Manner, that it's End *z* is very near the Bottom of it.

Cocks are join'd to the Cavities at *e*, *e*, *e*, *e*; or there are other Apertures in them, which are ſtopp'd by Screws, Leathers being put between; the chief Uſe of which is that the Cavities may be well emptied through them, leſt they ſhould ruſt in the Inſide.

Experiment 5.

Water is pour'd into the Pipe *o p*, with which the Cavity D is fill'd; and if you continue to pour the Water in it will aſcend along the Pipe *s t*, and deſcend along *q r* into the Cavity C, which is alſo fill'd, the Air aſcending along *x v* and going out through *z y*. Invert the Machine, removing the Screws *e*, *e*, of the Cavities C and D, and the Water will deſcend into the Cavities B and A. The Holes *e*, *e*, being ſtopt again, as alſo the Hole *y* of the Pipe *z y*, ſet the Machine upright, and pour Water again into the Pipe *o p*, 'till the upper Surface of the Machine be covered with Water. Now if the Hole *y* be opened, the Water will ſpout upwards to an Height almoſt double the Height *o p* (*Fig.* 5;) and the Motion of the Water will continue, 'till the Cavity C is emptied. The Height 2269.

of the ſpouting Water will be continually diminiſhed, and at the End it will be leſs than twice the Diſtance between the Veſſels.

2270. The Effect of this Machine muſt be attributed to the Compreſſion of the Air in the Veſſels. The Preſſure of the Atmoſphere at *o* and *y*, as alſo the Preſſures thence ariſing in the Veſſels themſelves, are equal; therefore theſe Preſſures mutually deſtroy one another, and are not to be taken Notice of in the Examination of the Machine. When at laſt Water is pour'd into the Pipe *op*, it is ſuſtain'd in it by the Preſſure of the Air contain'd in the Cavity D, and which acts upon the Surface of the Water, which takes up a ſmall Part of the Height of this Cavity; which Air therefore is compreſs'd by the Weight of the Water of the Height *po*: I ſpeak of the Preſſure, which overcomes the Preſſure of the Atmoſphere. The Air, contain'd in the upper Part of the Cavity B, communicates with the Air mention'd by the Pipe *st*, and is compreſs'd in the ſame Manner; and this acts upon the Surface of the Water in this Cavity with the ſame Force. This Preſſure muſt be ſuperadded to the Preſſure from the Height of the Water, that we may have the Force, with which the Air, which is contain'd in the Cavity C, is compreſs'd, as alſo that which is in the upper Part of the Cavity A, by Reaſon of the Communication by the Pipe *xv*. Therefore the Preſſure, which acts upon the Surface of the Water, in this Cavity A, is equal to a Pillar of Water, of almoſt double the Height of the whole Machine; and therefore the Water ſpouts, through the Hole at *y*, as if it were preſs'd by ſuch a Pillar; that is, it riſes to an Height, which wants but little of the Height of this Pillar *.

* 1588. This Height is continually diminiſhed; for the Pillars of Water, which compreſs the Air, are continually diminiſh'd; becauſe the Water is encreas'd in the Cavities C and D, and it's Height is diminiſhed in the Cavity B. At the ſame Time the Cavity A is continually emptying, and the Water riſes through a greater Space, before it comes to *y*; and it is therefore driven to a leſs Height above *y*.

CHAP.



Fig. 1.

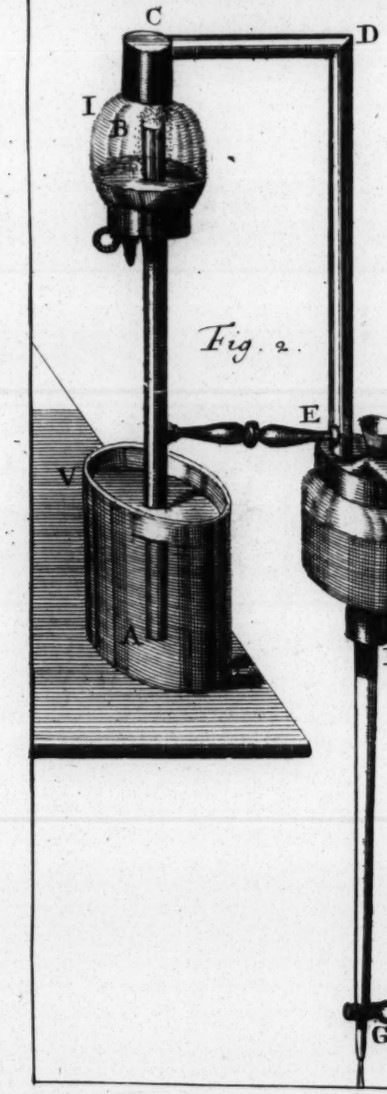


Fig. 2.

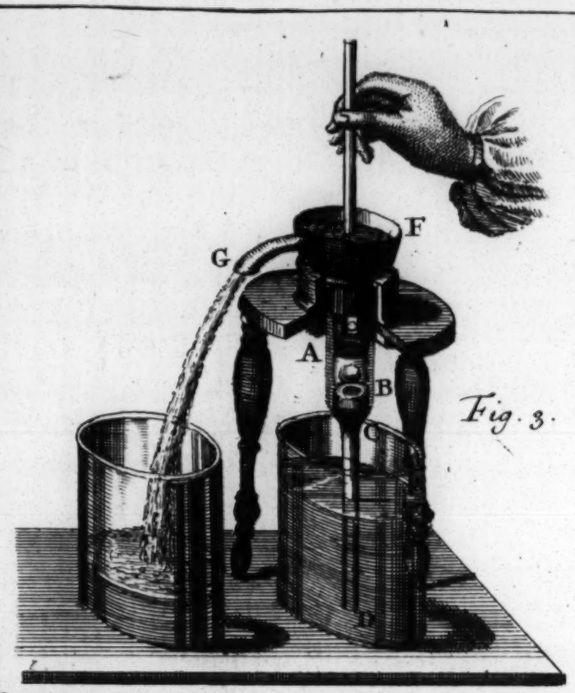


Fig. 3.

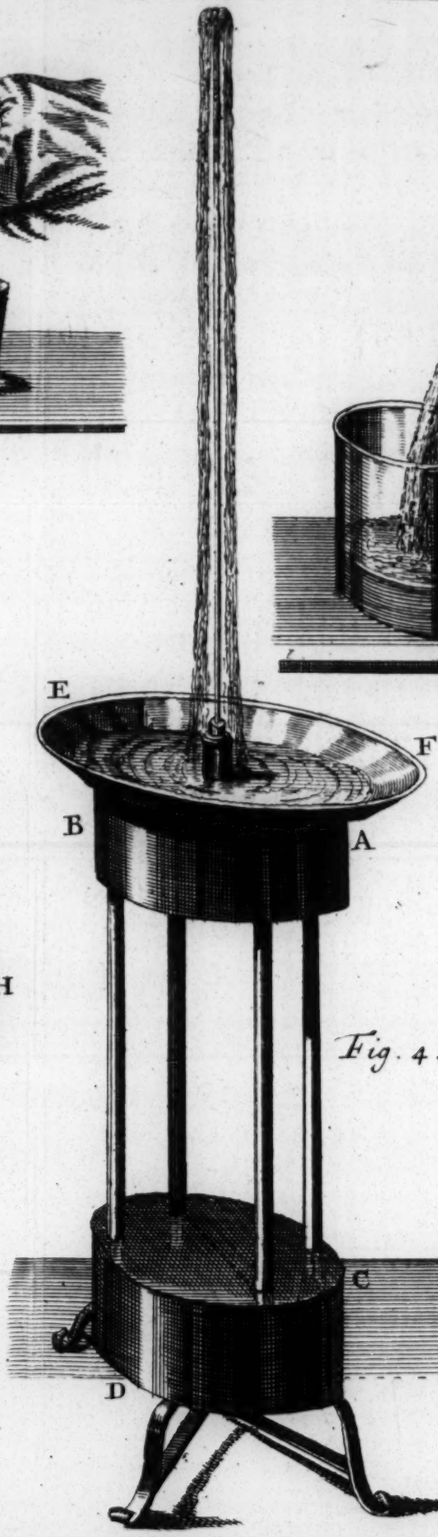


Fig. 4.

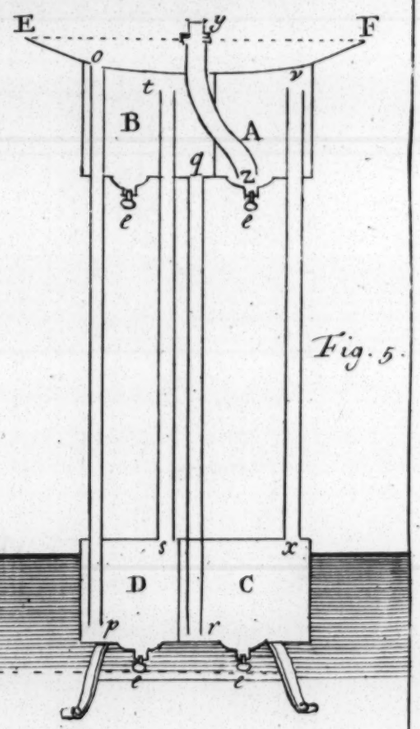


Fig. 5.

J. Mynde fc.

CHAP. VII.

Of the Undulatory or Wave-like Motion of the Air, as likewiſe concerning Sound.

IF the Air be any how agitated, the Particles mov'd go out of their Place, and cauſe the Particles next to them to poſſeſs a leſs Space; and whilſt the Air is dilated in one Place, it is compreſs'd in the Place next to it. The compreſs'd Air, whilſt, by Reaſon of the Elaſticity being encreaſs'd by the Compreſſion, it expands itſelf again, does not only return to it's firſt State, but is itſelf dilated by the Motion acquir'd by the Particles receding from one another beyond their firſt Diſtance. 2271.

The Air being firſt dilated by that Motion, returns to it's firſt State, and the Air towards other Parts is compreſs'd. This again happens, when the Air laſt compreſs'd expands itſelf, and thereby a new Compreſſion of Air is produc'd. Therefore *from any Agitation there ariſes a Motion analogous to the Motion of a Wave on the Surface of Water* *. And the Air thus compreſs'd, with a Dilatation following, is *call'd* by that ſame Name, *viz. a Wave of Air* *. * 1737. * 1738.

Compreſs'd Air dilates itſelf every Way, and *the Motion of theſe Waves, is the Motion of a Sphere expanding itſelf*, juſt as theſe Waves move circularly on the Surface of the Water *. 2272. * 1740.

Whilſt a Wave moves in the Air, wherever it paſſes, the Particles are mov'd from their Place and return to it, running through a very ſhort Space in coming and going. 2273.

To explain the Laws of this Motion, let us conceive Particles of Air to be plac'd at equal Diſtances, *a*, *b*, *c*, *d*, &c. and *f* in a right Line. Let the Wave move along that Line, and ſuppoſe it to be come forward, as far as between *b* and *p*; and that the Air is dilated between *b* and *h*, but compreſs'd between *h* and *p*; as all this is repreſented in Lines. 2274. Pl. 75. F. 1.

The greateſt Denſity is at m, *the Middle Point* t *between* h *and* p, *and the greateſt Dilatation is in the Middle* e *between* b *and* h. 2275.

Wherever the neighbouring Particles are not equally diſtant, by the Action of the Elaſticity the leſs diſtant Particles are preſs'd towards thoſe that are more diſtant *; and this Preſſure, ſetting aſide all Motion acquir'd, muſt be firſt examin'd into. 2276. * 2111.

2277. *Between* b *and* e *there is a Preſſure* from *b* towards *e*, that is, *conſpiring with the Motion of the Wave, and another ſuch between* m *and* p.

2278. But *there is a* contrary *Preſſure between* e *and* m, *from* m *towards* e.

2279. *At* m *and* e, where the Directions of theſe Actions are chang'd, the oppoſite Actions deſtroy one another; becauſe the adjacent Particles are ſuppos'd to be equally diſtant.

2280. *In the Places* b, h, *and* p the Difference of the Diſtances of the adjacent Particles is the greateſt of all; and therefore *the Action of the Elaſticity towards one Part is the greateſt of all.*

2281. From hence we gather that a Particle according to it's different Place in a Wave ſuffers a different Action from the Elaſticity by which it's Motion is generated, accelerated, diminiſh'd, or deſtroy'd. Therefore the Direction of the Motion of a Particle cannot be determin'd from the Direction alone of the Action mention'd, and that does not always agree with this Direction, and the Motion of every one of the Particles is chang'd every Moment.

2282. All the Particles between *b* and *p* are carried according to the Order of the Letters. The Particles, between *h* and *p*, continue their Motion in this Direction; and the reſt between *h* and *b* return towards *b*, as we ſhall ſee hereafter.

2283. Theſe continue in the Motion by which they return, until, by the Action of the Elaſticity, whoſe Direction is chang'd in the Point *e*, the Motion acquir'd anew be deſtroy'd; in which Caſe a Particle, as *b*, returns to Reſt in it's former Situation. In the next Moment the Particle *c* comes to Reſt in it's former State, but *p* comes on to *q*, as in Line 2; and in equal Moments, the Wave ſucceſſively has all the Poſitions, as you ſee here in the Lines 1, 2, 3, &c. and 13; and

2284. *whilſt the Wave* comes from the Poſition in the Line 1, to the Poſition in the Line 13, it *runs through it's whole Breadth. The Particle* p in this Motion *goes and comes*, and it's Motion is ſenſible in this Figure; *and* this Particle *goes ſucceſſively through all the Poſitions of the Particles in the Wave*, as is manifeſt.

2285. All the Particles are ſucceſſively agitated with a like Motion: And *if the Time, in which a Wave runs through it's Breadth, be divided into ſo many Parts as there are Particles in the Breadth of the Wave, every Particle will be found in that Poſition in which the following Particle was the Moment aforegoing*, which was longer in Motion by one ſuch Moment.

The

The Motion of any Particle, as *p*, *in going backwards and forwards, is analogous to the vibrating Motion of a Pendulum, whilſt it* performs two Oſcillations; that is, once *goes* and once *returns.* 2286.

A Pendulum deſcends in it's Oſcillation, and the Motion acquir'd conſpires with the Action of Gravity, and is accelerated by it, until it comes down to the loweſt Point of the Arch to be deſcrib'd, that is, to the Middle of the Way to be mov'd through; the Pendulum goes on by the Motion acquir'd, which is deſtroy'd by the Action of Gravity, whoſe Direction changes in this Point, whilſt the Body riſes up the other Part of the Arch to be deſcrib'd: This Body goes back with the ſame Laws. 2287.

The Particle *p* is mov'd by the Elaſticity, and it's Motion is accelerated by the Action of the Elaſticity, until it comes to the Situation of the Particle *m*, in the Line 1 *; which Situation appears in the Line 4, in which the Particle *p* takes up the middle Point of the Space, to be run through, in coming and going. Though the Elaſticity acts contrary to the Motion acquir'd *, yet it continues it's Motion, until the Motion be quite deſtroy'd by the Action of the ſaid Elaſticity; which happens when it has gone through a Space equal to that, in which it was generated; then the Particle *p* is in the Situation, appearing in the Line 7, which anſwers to the Situation of the Particle *h* in the Line 1. Then the Particle returns by it's Elaſticity, and is accelerated, until it has acquir'd the Situation of the Particle *e* of the Line 1 *, as in the Line 10; that is, until it comes again to the Point that is in the Middle of the Way to be run through, as in the Line 4. The Particle continues returning until the whole Motion be deſtroy'd by the Action of the Elaſticity, whoſe Direction is again chang'd *; and then the Particle returns to it's firſt Poſition, as in the Line 13, and there not being agitated by any new Motion, remains at Reſt. All which Things flow from what is demonſtrated in the firſt following Scholium. Therefore *when the Motion of a tremulous Body, which agitates the Air, ceaſes, there are no new Waves generated*, and the Number of the Waves is the ſame as the Number of the Agitations of that Body. 2288. * 2277. * 2278. * 2278. * 2279. 2289.

If the Action of Gravity ſhou'd ceaſe after two Vibrations of a Pendulum, as in the Air after the going and returning of a Particle, the Action of the Elaſticity upon that Particle ceaſes; the Motion of a Particle of Air, wou'd in all Things agree with the Motion of the Pendulum. In the middle Point of the Arch, which is to be run through by the Oſcillation, there is no Action of Gravity, and the 2290.

the Direction thereof is chang'd; in the middle Point of the Space to be mov'd through, by the Particle *p* in it's going and coming, in which it is in the Line 4 and 10, the Situation of this Particle anſwers to the Situation of the Particles *m* and *e*, in the Line 1, in which Points there is no Action of Elaſticity, and it's Direction is
* 2279. chang'd *. In a Pendulum, the more a Body oſcillating is diſtant from the loweſt Point, or middle of the Arch to be deſcrib'd, the more does the Force of Gravity act upon it; alſo the more diſtant the Particle *p* is from the middle Point of the Space to be run through, the greater is the Action of the Elaſticity upon it, and in the Lines 1, 7, and 13, in which the Particle is moſt diſtant from the Point abovementioned, the Situation of it agrees with the Points *b*, *b*, and *p*, in the Line 1, in which the Action of the Elaſticity
* 2280. is greateſt of all *.

2291. By which Law is determin'd the Action of the Elaſticity, ſince it increaſes when the Diſtance from the often-mention'd middle Point increaſes, from the Law of the Elaſticity of the Air itſelf, whoſe Particles fly from one another with a Force which is inverſly
* 2111. as the Diſtance between the Centers of the Particles *; and we demonſtrate in the firſt Scholium annexed to this Chapter, that the Action of the Elaſticity upon a Particle, as *p*, increaſes or diminiſhes in Proportion to it's Diſtance from the middle of the Space to be run through.

2292. For which Reaſon, *every Particle in it's Motion goes and returns, according to the Law of the Motion of a Pendulum oſcillating in a*
* 414. *Cycloid* *.

2293. We demonſtrate in the ſame Scholium, that *the Velocity of a Wave is equal to that Velocity which a Body acquires in falling from one half the Height that the Atmoſphere would have, if, whilſt the Quantity of the Air remains the ſame, it ſhould every where have that Denſity, which it has in the Place wherein the Wave moves.* And the Demonſtration obtains whatever be the Breadth of the Wave, and whether the Particles in going and coming run through a greater
2294. or leſs Space; whence it is evident that *all Waves move with the ſame Velocity*; namely as long as the ſaid Height of the Atmoſphere is not alter'd, ſuppoſing it to be every where of the ſame Denſity.

2295. But this being chang'd, *the Squares of the Celerities of the Waves*
* 2293. *are in the Ratio of the Heights* *. But this Height often varies; for
374. the Denſity of the Air often alters *the Elaſticity remaining the ſame*;
2296. and the Elaſticity may be chang'd while the Denſity remains the ſame; laſtly they very often both together change.

In the firſt Caſe, *viz*, when the Elaſticity remains, and the Denſity varies, whilſt the Air is ſuppos'd every where of the ſame Denſity, the Height is chang'd, but the Quantity of the compreſſing Air does not vary; becauſe the Weight thereof is equal to the Elaſticity *: And the Height is as the Space taken up by the Air; and ſo is inverſly as the Denſity †; wherefore *the Squares of the Velocities of the Waves are inverſly as the Denſities* *. * 361. † 1464. * 2295.

When the Denſity remains the ſame, but the Elaſticity varies, the Height of the Atmoſphere is chang'd in the Ratio of the compreſſing Weight, that is, in the Ratio of the Elaſticity *. Therefore *the Squares of the Velocities of Waves are as the Degrees of Elaſticity* *. 2297. * 361. * 2295.

If both the Velocity and Denſity differ, the Squares of the Velocities of the Waves will be in a Ratio compounded of the direct Ratio of the Elaſticity †, *and of the inverſe Ratio of the Denſity* *. 2298. † 2297. * 2296.

If the Denſity and Elaſticity increaſe or decreaſe in the ſame Ratio, the inverſe Ratio of the Denſity deſtroys the direct Ratio of the Elaſticity, and *the Velocity of the Waves will not be chang'd.* 2299.

This laſt Caſe happens in the Compreſſion of the Air ariſing from other Air mixing with it *, whereby, if the Tenor of the Air remains the ſame as to the reſt, the Height of the Atmoſphere, ſuppoſing it to be every where of the ſame Denſity, is not alter'd; for it is reduc'd into a leſs Space in Proportion to the ſuperadded Weight. Therefore *from the chang'd Height of a Column of Mercury, which is ſuſtain'd in a Tube exhauſted of the Air* * *by the Preſſure of the Atmoſphere*, which ſhews that the Weight, by which the Air is compreſs'd near the Earth, is chang'd, *we cannot be certain whether the Velocity of the Waves does alter.* For the ſame Reaſon *the Waves are mov'd with the ſame Velocity in the Top of a Mountain as in a Valley, if the Tenor of the Air does not differ* according to the greater Height *. * 2109. 2300. * 2085. 2301. * 2123.

That *Waves move faſter in Summer than in Winter* is deduc'd from the Elaſticity of the Air being increas'd by Heat *. 2302. * 2117.

The Height of the Atmoſphere, ſuppoſing it to be every where of the ſame Denſity, is found out by meaſuring the Height of the Column of Mercury in the *Torricellian* Tube, which is balanc'd by the Preſſure of the Atmoſphere *, and by comparing the Denſity of the Air with the Denſity of the Mercury; which may be done by weighing the Air *. And when the Height of the Air is found out, the Velocity is had by Experiments of Pendulums, which a Body acquires in falling from one half that Height *. 2303. * 2085. * 2164. * 415.833.374.

The

2304. The Motion of the Air, which is conſider'd in this Computation, depends wholly upon the Elaſticity, and the Computation would be exact, if the Particles themſelves had not a ſenſible Proportion to the Interſtices between them; but if we ſuppoſe here that the ſaid Proportion is ſenſible, the Motion of the Waves will be ſwifter; for Motion is propagated through ſolid Bodies in an Inſtant.

2305. But *we have conſider'd the Particles of the Air as Points, and the Velocities found out upon this Suppoſition, muſt be increas'd in Proportion of the Matter to the Interſtices, in order to have the true Velocity.*

2306. Wherefore *ſo long as the ſame Air preſerves it's Denſity, the Augmentation of the Velocity is in the ſame Ratio with the Velocity itſelf.*

2307. But *if the Denſity is chang'd, the Augmentation is* not only *in the Ratio of the Velocity*, but *alſo in the Ratio* of the Matter to the Matter in the ſame Line, which is the Ratio *of the Cube Root of the Denſity.*

2308. *If the Air be different, this Rule does not obtain*, for the Particles themſelves, when the Denſity remains the ſame, may have a different Denſity; and the Ratio of the Diameters of the Particles to the Interſtices will be alter'd.

2309. *The Motion of the Waves in the Air produces Sound*; but before we treat concerning this, we muſt premiſe a few Things in general relating to the Senſations.

2310. So ſtrict is the Union between the Body and the Mind, that ſome Motions in the Body do as it were cohere with certain Ideas of the Mind, and they cannot be ſeparated from each other. New Ideas are every Moment excited in the Mind, by the Motion of the Nerves, and ſuch are the Ideas of all ſenſible Objects; yet we find nothing common between the Motion in the Body and the Idea in the Mind. We cannot perceive their Connexion, or whether there be any at all. There are innumerable Things in Nature hidden from us, which even our Ideas cannot attain to. But this Connexion does not relate to Phyſicks.

2311. When a Senſation is to be explain'd in Phyſicks, we ought to ſhew how the Motion of a Body, which Cauſes Senſation, acts upon our Nerves.

2312. Therefore three Things relating to Sound are to be conſider'd; 1. we muſt determine the Motion in a Body which produces Sound; 2. We muſt ſhew how theſe Motions are transfer'd to us; 3. Laſtly we muſt explain what happens in us.

The Parts of Bodies, which emit Sound, are put into a tremulous Motion; for non-elaſtic Bodies, when ſtruck, do not produce Sound. This tremulous Motion is alſo undoubtedly in ſtretched Chords or Fibres, from whence proceeds the Sound. This tremulous Motion is very ſenſible in large Bells, and in many other Bodies; it is viſible from the following Experiment with a Glaſs Bell, which gives a Sound. 2313.

EXPERIMENT 1.

A thin Glaſs Bell, which has a Knob at Top, that it may be held in the Hand, is ſtruck, and the Edge of it is brought near any ſolid Body at reſt; if the Diſtance be ſmall, the Bell will, by Means of it's tremulous Motion, ſtrike againſt this Body ſeveral Times. 2314.

Yet *the Sound does not immediately depend upon this viſible Motion, but upon another tremulous Motion, with which the ſmaller Particles are affected, in the Motion mention'd.* 2315.

EXPERIMENT 2.

The elaſtic Iron Plate A C B, being ſuſpended, is put into a tremulous Motion which is viſible, if the Ends A and B are brought together, and ſuddenly let go; yet no Sound is heard: But if it be ſtruck on the Sides, which does not put it into a tremulous Motion that is viſible, there is a Sound produc'd. 2316. Pl. 76. F. 1.

A Body that is ſtruck, continues to give a Sound ſome Time after the Blow; for the agitated Fibre will continue it's Vibration ſome Time, on Account of the Elaſticity *. 2317. * 1332.

Sound alſo *ceaſes when the tremulous Motion ceaſes.* 2318.

From a Body, thus agitated, Motion is transfer'd to the Ear by Means of the *Air*; for Experience ſhews that this *is the Vehicle of Sound.* 2319.

A MACHINE,

Whereby Experiments concerning Sound are made.

The Machine A, to which is join'd the little Bell C, (which is repreſented ſeparately in Fig. 5, that it may the better appear how it is to be join'd to it,) contains ſeveral ſmall Wheels, to which Motion is communicated by a Spring, as in Watches; and which move the ſmall Hammers *m*, *m*, that ſtrike the Bell alternately. It is requir'd that this Motion be continued four or five Minutes, before the Spring be let looſe. 2320. Pl. 75. F. 2. 5.

2321. By the Plate *e*, the Motion of the Wheels, and the Hammers, is ſtopp'd, or continu'd; this depends upon the Poſition of the Plate which may be varied, whilſt it is moveable about *c*, and can retain the Plate *d*, which coheres with an Axis, and in it's Motion goes and returns round a Center.

EXPERIMENT 3.

2322. This Machine coheres with the Leaden Stand D, and, the ſmall
Fig. 2. Cuſhions E, E, being put between, is put upon the Plate G of the Air-pump, and is cover'd with the Glaſs Receiver R, open at Top. This Aperture is clos'd by the Cover O, to which is faſten'd the
* 2155. Collar of Leathers P, which the Braſs Wire S T goes through *; to the End T of this Wire is join'd the Plate B, which is ſo bent and cut in, that by turning the Handle, the Poſition of the Plate *e* may be alter'd; whereby the Hammers are retain'd, or let looſe, as you pleaſe. The Hammers being fix'd, the Air is exhauſted from the Receiver, the Hammers are let looſe, and no Sound is heard.

2323. All the Sound cannot always be extinguiſh'd, but it may be ſo weaken'd, as to be perceiv'd only by thoſe, whoſe Hearing is pretty quick.

2324. The Mercurial Gage alſo, in this Experiment, does not ſhew that all the Air is exhauſted; for when the Mercury is come to it's greateſt Height, the Motion of the Pump muſt be continued, that the Sound may be extinguiſh'd, or weaken'd as much as poſſible; by which is confirm'd what we ſaid before, that the Den-
* 2190. ſity is diminiſh'd, the Elaſticity remaining the ſame *.

2325. A ſmall Quantity of Air being let in, we immediately perceive a Sound, which is increas'd with the Air that is let in. This Experiment puts it out of all Doubt, that Sound is propagated by Air, but in this Motion the Air is not carried from one Place to another;
2326. whence appears what we ſaid, that *Sound depends upon the undula-*
2327. *tory Motion of the Air*; by which is confirm'd, that *Sound ariſes from the tremulous Motion of Bodies.*

But as this tremulous Motion is eaſily communicated from one
2328. Body to another, *The Conveyance of the Sound, from the tremulous Motion of the Fibres, is very remarkable*; and how far the Communication of this Motion extends itſelf, will appear from one Experiment only.

EXRE-

EXPERIMENT 4.

Things being diſpos'd, as in the foregoing Experiment, and the Air being exhauſted, and the Hammers being let looſe, the Handle M is turn'd in ſuch Manner, that the Plate B may touch the Plate *e*, but not alter it's Poſition; at that very Moment a Sound is heard; the Sound of the Bell indeed is weak, but the Sound of the Wheels is perceiv'd very diſtinctly; the Plates being again ſeparated the Sound immediately ceaſes. 2329.

In the third Experiment, before the Air was exhauſted, and after it is again let in, the Sound might be perceiv'd, though the agitated Air had no Communication at all with the external Air; whence it follows, that *the undulatory Motion of the Air communicates a tremulous Motion to the Fibres of Bodies, whereby Waves are generated in the exterior Air.* But in this Caſe the Sound is very much weaken'd. 2330.

As *Sound is propagated* through ſolid Bodies, ſo likewiſe is it *through Fluids*; but *in this laſt Caſe it is alſo very much weaken'd.* 2331.

EXPERIMENT 5.

The Machine deſcrib'd above * is inclos'd in the Glaſs V, the Hammers *m*, *m*, being firſt let looſe; the Glaſs is clos'd with the Wooden Cover O, and the Water is hinder'd from getting in by ſoft Wax. This Glaſs is put into a greater Glaſs B, which contains Mercury in it to the Height of one, or two Inches, and the Glaſs B is fill'd with Water. A Sound is heard, but it is weak. 2332. Pl. 75. F. 3. * 2320.

But there is no Communication between the Bell and the external Air, unleſs through the Fluids, Water or Mercury.

The Fluid communicates a tremulous Motion to the Glaſs itſelf, in which it is contain'd, and to the Air, which is upon the Surface of the Water. 2333.

In all theſe the undulatory Motion comes to the Ear, and goes into a Canal, in the external Part of the Ear; this external Part is terminated by a very thin, ſtretch'd Membrane, call'd the Tympanum, or Drum of the Ear, and which ſeparates the external Part of the Ear from the internal. The Particles of Air, which are near this Membrane, when the undulatory Motion reaches them, ſtrike the Drum of the Ear, and communicate a tremulous Motion to it, which is transfer'd to the Air inclos'd in the inward Cavity of the Ear; ſome ſmaller Bones are mov'd, by the Agitation of the Drum; the undulatory Motion is propagated through certain ſmall Canals, 2334.

which are twiſted in a peculiar Manner, and the whole bony Surface of this Cavity is ſtruck by the Particles of Air, which are in Motion. By all theſe Motion is eaſily communicated to the auditory Nerve, which coheres with the Organ, of which we are ſpeaking, and which goes into the Cavity itſelf of it.

2335. The Structure of the Ear is wonderful, but as we are not acquainted with the Uſe of the peculiar Parts, the general Things only, which we have taken Notice of, belong to our Purpoſe.

2336. *The Celerity of Sound is the ſame as the Celerity of Waves, which ſtrike the Ear*, and to this muſt be refer'd what has been ſaid of their Celerity *. In reſpect to Numb. 2293 it is to be obſerved, that the Celerity of Sound can no Way be determin'd by Calculation * ; for the Proportion between the Diameters of the Particles and the Interſtices between them, is not known ; but the Celerity of Sound may be immediately determin'd by an Experiment.

* 2293. 2294. 2296 2297. 2298. 2299. 2300. 2301. 2302. 2305. 2306. 2307. 2308. * 2303. 2304.

2337. If a Flaſh of Fire goes off at Night with a Noiſe, and a Spectator ſtands at any known Diſtance from the Fire, who, with a ſhort Pendulum, meaſures the Time between ſeeing the Light, and hearing the Sound, he will have the Celerity of the Sound ; for the Motion of Light, at leaſt, through the Space as ſuch an Experiment can be made in, is inſtantaneous.

2338. By ſuch an Experiment made in *France*, it appear'd, that Sound mov'd 1080 *French* Feet, that is, 1117 *Rhinland* Feet in one Second of Time : Which Velocity differs little from that, which *Durham* determin'd from many Experiments, in a Space exceeding twelve *Engliſh* Miles ; according to whom the Space run through in one Second is 1100 *Rhinland* Feet : But this Celerity is not conſtant *.

* 2302.

2339. If at the ſame Time in which the Velocity of Sound is determin'd by this Method, you find out the Space mov'd through by the Elaſticity *, the Acceleration of the Sound will be had from the Thickneſs of the Particles.

* 2293. 2303.

2540. *The Celerity of Sound is equable* * ; *yet in going through a greater Space it is ſometimes accelerated or retarded* †, from the different repellent Force, which the Particles ſometimes have in different Places *. But this is deduc'd rather from Reaſoning than Experience, becauſe the Conſtitution of the Air does not differ enough in neighbouring Places.

* 2294. † 2296. * 2117.

2341. *The Celerity of Sound varies as it goes with the Wind, or againſt it.* By the Wind a certain Quantity of Air is carried from one Place to another ; the Sound is therefore accelerated as long as it

moves through that Part of the Air, if the Direction of the Sound be the ſame with the Direction of the Wind; in which Caſe the Velocity of the Wind muſt be ſuperadded to the Velocity of Sound, which has been taken Notice of.

But the Velocity of the moſt violent Winds, which is ſtrong enough to root up Trees, and blow down Houſes, is leſs than a thirtieth of the Velocity of Sound, if with *Mariotte* we ſuppoſe, the moſt violent Wind to run through only thirty two Feet in one Second. 2342.

According to others the Velocity of Wind is much greater, and therefore the Acceleration of Sound is greater, which agrees better with Obſervations. 2343.

By the Way of arguing it is alſo prov'd that Wind retards the Motion of Sound. 2344.

The Spaces which the Particles run through, as they come and go, may be increas'd and diminiſh'd by the Wind; therefore *the Sound may be heard at a greater or ſmaller Diſtance, according to the Direction of the Wind.* For in the Air which is mov'd by the Wind, there is a certain, ſmall mutual Acceſs of the Particles, whilſt the hinder Air drives on that which is before it; by this the Elaſticity of the Air is increas'd, and the Direction of this mutual Motion conſpires with the Direction of the Wind. 2345.

The Intenſity of Sound depends upon the Strokes of the Air upon the auditory Nerve; and theſe Strokes are as the Quantities of Motion of the Particles ſtriking. 2346.

Theſe Forces are as the Number of the Particles ſtriking againſt the Drum of the Ear at the ſame Time, and as the Squares of the Velocities of theſe Particles *. 2347. * 757.

Therefore *in determining the Intenſity of Sound, the Denſity of the Air muſt be conſider'd, the Velocity of the Sound, the Space mov'd through by the Particles in going and returning, and the Number of the Waves ſtriking the Ear in a certain Time.* 2348.

All things remaining as before, if the Weight by which the Air is compreſs'd be only *chang'd*, the Space mov'd through by the Particles in going and coming will not by that be chang'd, which only varies upon the Augmentation or Diminution of the tremulous Motion of the Parts of a Body; nor will the Number of the Waves be chang'd, for theſe alſo depend upon the tremulous Body; neither is the Velocity of the Sound alter'd *, ſetting aſide the Acceleration, mention'd in Number 2305. which is not to be conſider'd here, becauſe in this Place the Velocity we are treating of, is that with 2349. * 2300.

which

which every Particle is mov'd; therefore the Denſity only varies, that is, the Number of Particles moving in a given Time is only chang'd, and *the Intenſity of the Sound is chang'd* in this Ratio *; that is, in the Ratio of it's Denſity, which is *in the Ratio of the compreſſing Weight* *.

* 2346.

* 2101.1464.

It appears by Experiment that the Intenſity of it is encreas'd.

Experiment 1.

2350. Plate 75. Fig. 4, 5. * 2216. † 2320. * 2322. * 2155. * 2322. * 2224.

The Board, part of which is repreſented ſeparately at E, is put into the Machine N M, in which the Air is compreſs'd *. Upon this Board we put the Machine A †, a Leather being put between, which we made Uſe of in the third Experiment of this Chapter *; aud that it may not be remov'd from it's Place, the Leaden Stand D has two Holes in it; that Pins, faſten'd to E, one of which is ſeen at *f*, may go into theſe Cavities. To the Cylinder N M is join'd the Collar of Leathers *p*, through which the Braſs Wire S T goes *, to which is faſten'd the Plate B, which we made Uſe of in the third Experiment *, but it is applied to the Wire in another Manner; by this, in this Caſe, as in that, the Hammers are kept from moving, or they are let looſe, by turning the Handle Q.

The Cylinder M N is clos'd by the Cover O, and the Air is compreſs'd as much as you pleaſe *, and the Machine is again put upon it's Stand G. The Hammers being let looſe, the Sound is heard diſtinctly, and the better, the more the Air is compreſs'd. If you open the Cock, and let the Air out, and ſhut it again, the Sound is faint.

2351. As the Intenſity of the Sound is greater in compreſs'd, inclos'd Air, the Fibres, of which the Cylinder M N conſiſts, are agitated more alſo, and a greater Agitation is communicated to the outward Air.

2352. 2109. *If, the compreſſing Weight remaining the ſame, the Denſity be encreas'd*, the Matter mov'd is indeed encreas'd in the ſame Ratio with the encreas'd Denſity; but we demonſtrate in the ſecond Scholium, annexed to this Chapter, that *the Intenſity of Sound*, in this Caſe, *is diminiſh'd in the Ratio, in which the ſquare Root of the Denſity encreaſes*. From whence it follows, that *in Summer, cæteris paribus, the Intenſity of Sound is greater than in Winter*.

2353.

Experiment 7.

2354. Pl. 76. F. 2 Suſpend the Bell A in the Glaſs R; and, when the Cock is open'd, let the Air in the Glaſs communicate with the outward Air. Shake

the Glaſs, and obſerve the Diſtance, at which the Sound can be heard. The Glaſs being heated together with the internal Air, and the Experiment being repeated, the Sound will be heard at a greater Diſtance.

Theſe Things are ſo, as long as the Temper of the Air remains the ſame; but this is often chang'd *. *Watery Vapours hinder the Intenſity of Sound very much.* 2355. * 2117.2122.

There is alſo a Diſtance of Sound ariſing from the Number of the Vibrations of the Fibres of the ſonorous Body; that is, from the Number of the Waves produc'd in the Air in a certain Time; for according to the different Numbers of the Percuſſions againſt the Ear, the Mind receives a different Senſation. 2356.

A muſical Tone depends upon this Number of Vibrations, which is ſaid to be ſo much the more acute, as the Returns in the Air are more frequent, and the more grave, the leſs the Number of Waves is. 2357.

And the Degrees of the Sharpneſs of different Tones, are to one another as the Number of the Waves, which are produc'd in the Air at the ſame Time. 2358.

A Tone does not depend upon the Intenſity of the Sound; and an agitated String gives the ſame Sound, whether it goes and comes along a greater, or leſs Space *. 2359. * 1292.2357.

Concords ariſe from the Agreement between the different Motions in the Air, which affect the auditory Nerves at the ſame Time. 2360.

If two tremulous Bodies perform their Vibrations in the ſame Time, there will be no Difference between the Tones; and *this Agreement*, which is the moſt perfect of all, *is call'd an Uniſon.* 2361.

If the Vibrations be as One to Two, this Concord is call'd an Octave or Diapaſon. 2362.

If they be as Two is to Three, that is, if the Second Vibration of one Body always agrees with the third of another, *ſuch a Concord is call'd a Fifth or Diapente.* 2363.

Vibrations which are as Three is to Four, produce a Concord call'd a Fourth or Diateſſeron. 2364.

A Ditone is when the Returns of the Air are as Four is to Five. 2365.
And *a Seſquiditone is a Concord ariſing from the Concurrence of the fifth Vibration of one Body with the Sixth of another.* 2366.

Concords produc'd from the Agitations of Strings, if they be of the ſame Kind, are eaſily determin'd from their Dimenſions and Tenſion; for the Agitations of the ſmall Parts do depend upon the Agitations of the whole Strings. 2367.

Cæteris

2368. *Cæteris paribus, if the Lengths of two Strings be to one another as the Number of Returns in a Concord, the Concord or Conſonance*
* 1294. *between the Sounds, which the Strings produce, will be had* *.

2369. *The ſame will happen, if, cæteris paribus, the Diameters have the*
* 1295. *aforeſaid Proportion* *.

2370. *Alſo if, cæteris paribus, the Proportion of the Vibrations in a Con-*
* 1293. *cord be given between the ſquare Roots of the Tenſions* *.

2371. And *generally, ſuppoſing any Strings of the ſame Kind, if the Ratio compounded of the direct Ratio of the Lengths, and that of the Diameters, and of the inverſe Ratio of the ſquare Roots of the Tenſions, be the Ratio between the Numbers of the Vibrations perform'd in the ſame Time in any Conſonance whatever, you will have that Conſo-*
* 1296. *nance by the Agitation of theſe Strings* *.

Muſicians have confirm'd all theſe Things by Experiments.

They have obſerv'd a very notable phenomenon about theſe Strings, whoſe different Caſes are well worth explaining.

2372. *Let any muſical Strings be ſo ſtretch'd as to perform their Vibrations in the ſame Time; if one of them be agitated, the other will be mov'd alſo.* For every Wave of the Air ariſing from the tremulous Motion of the firſt String, ſtrikes the ſecond String, and communicates a ſmall Motion to it; and it goes backwards and forwards
* 1292. ſeveral Times, from the leaſt Motion *, being mov'd by the Stroke of the firſt Wave, whilſt the ſecond Wave comes forwards, whoſe
* 1292. Motion conſpires with the Motion of the String *; and accelerates it. What is ſaid of the ſecond Wave is true of the other Waves which follow, and there will be an Acceleration till the Motions of the Strings be nearly equal.

2373. It follows from the ſame Demonſtration, that *the String mov'd communicates Motion to the other, which performs two or three Vibrations whilſt the firſt performs one.*

2374. And if the agitated String performs various Vibrations, whilſt the String which is to be mov'd by the Air can perform only one, it will follow from the Demonſtration aforegoing, that it muſt communicate a particular Motion to it: To find out which, it muſt be obſerv'd, that the Duration of the Vibration, and the Length of the String are reciprocal in ſuch Sort, that every Thing elſe continuing as before, the determin'd Length can no Way be ſeparated from the determinate Duration of the Vibration. If therefore any String be ſtruck with ſeveral Strokes, by which Motion is communicated to it, and the Strokes are more frequent than what is agreeable to the Length of the String, that Part of it whoſe Length agrees with the

a b c d e f g h i l m n o p q r s t v u x y z a b c d e f

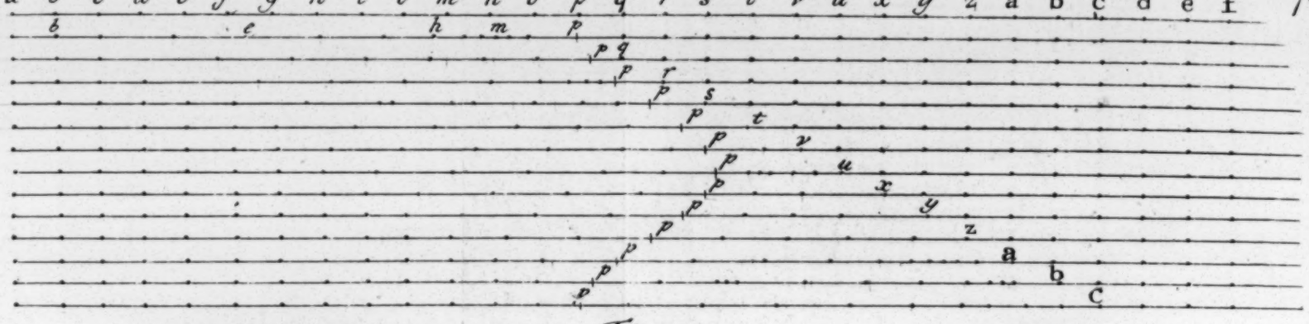


Fig. 1.

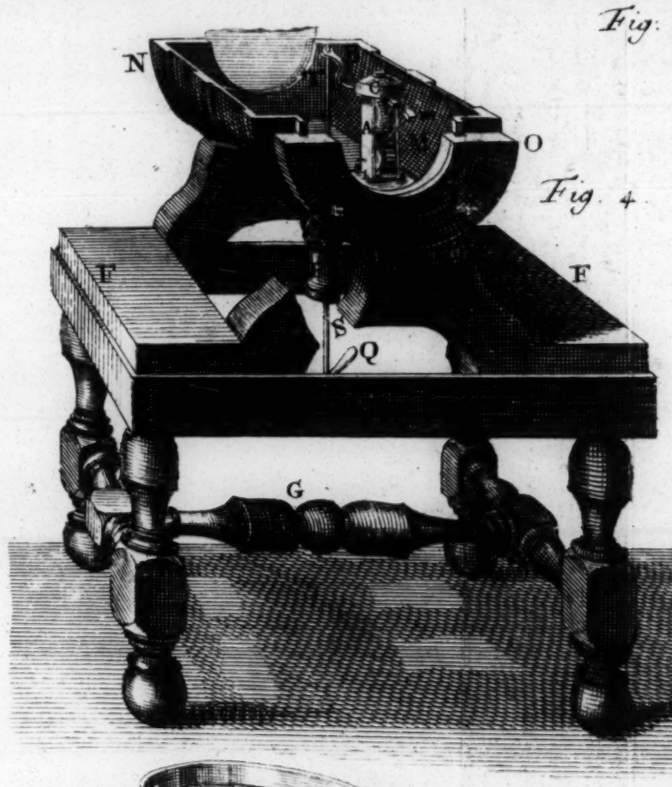


Fig. 4

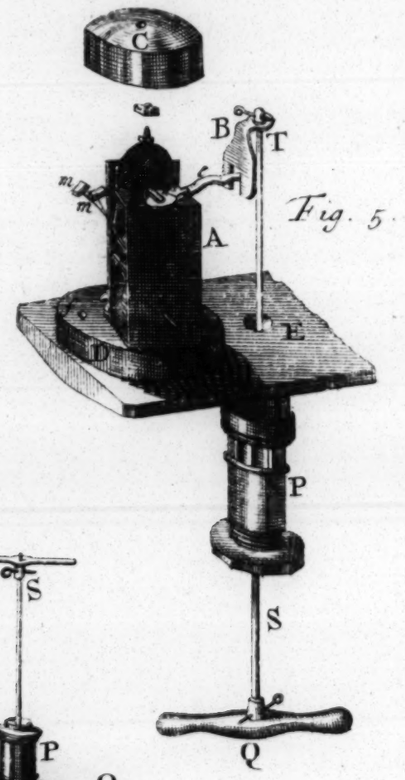


Fig. 5

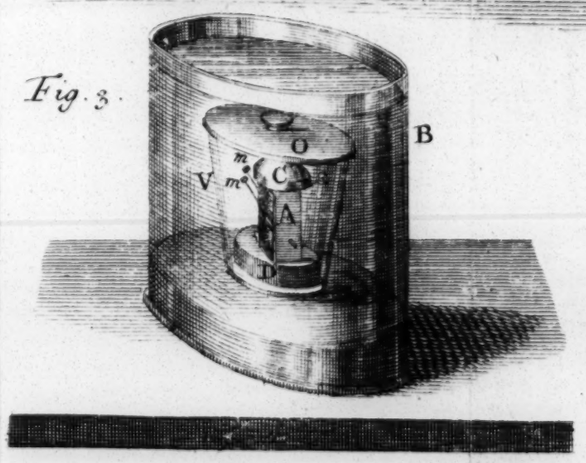


Fig. 3.

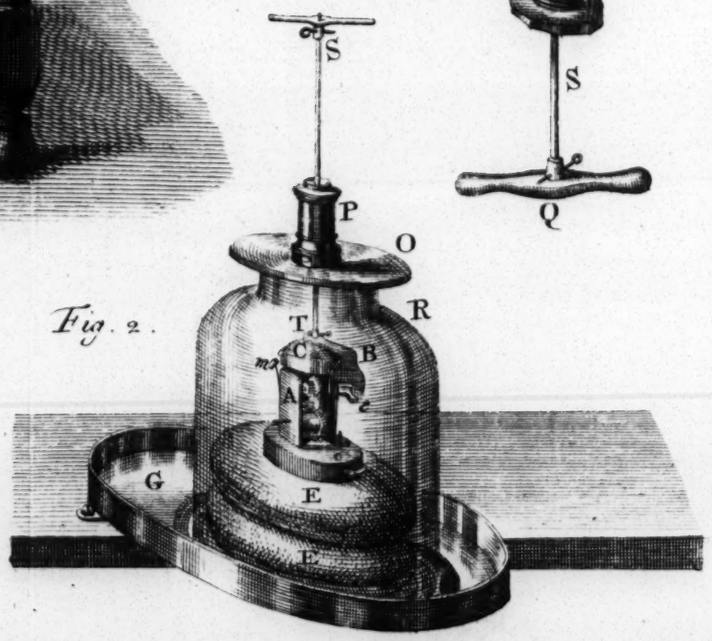


Fig. 2.

J. Mondo sc.

the Duration of the communicated Vibrations, will be agitated only, and there will be a Sort of undulatory Motion communicated to the String; and the Length of the Waves in the String will depend upon the Duration of the Vibration that is communicated, that is, upon the Time between the Strokes.

Let there be two Strings, the one of which vibrates twice whilſt the other vibrates once, and let the firſt String be put in Motion, the Duration of the Vibrations communicated to that String by the Motion of the Air, agrees to a String of half it's Length *, and ſuch is the Length of the Waves in it. Therefore *the String is divided into two equal Parts by the communicated Motion, and the middle Point is at Reſt.* This is confirm'd by an Experiment, *viz.* laying a Piece of Paper upon a String, to which the Motion is communicated; for if it be put upon the middle Point of the String it will be at Reſt, though in every other Place it will be affected with a tremulous Motion. 2375. * 1294.

If one String which is put in Motion in order to cauſe Motion in another, performs three Vibrations whilſt the String to be mov'd performs but one, this laſt will be divided into three Parts by the Motion communicated, and there will be two Points of Reſt; which is likewiſe confirm'd by an Experiment like that above-mention'd. All other Caſes of communicated Motion, which Muſicians have obſerv'd, are eaſily deduc'd from what has been ſaid. 2376.

What has been ſaid of the Reflection and Inflection of the Waves in Water *, may be refer'd to the Reflection of the Waves in the Air; the Elaſticity in this Caſe producing the ſame Effect as the Preſſure of the rais'd Water in that. 2377. * 1742. 1744. 1745. 1746.

From the Reflection of Sound there often ariſes a Repetition of it, which is call'd an Echo. If the ſeveral Parts of the ſame Wave, expanding itſelf ſpherically *, ſtrike upon different Surfaces, ſo that being reflected they meet, the Motion of the Air will be ſtronger there, and the Sound will be heard. *The ſame Sound is often repeated ſeveral Times*, from the different Parts of the ſame Wave reflected to different Diſtances, ſome of which alſo ſucceſſively meet in the ſame Place. Sometimes we have ſuch a Repetition from the Repetition of Reflection. 2378. * 2272. 2379.

Sound is encreas'd by Reflection in a Tube, as we find in ſpeaking Trumpets. The moſt perfect Figure that theſe Tubes can have, is that generated by the Rotation of a Parabola about a Line parallel to the Axis, at the Diſtance of a Quarter of an Inch. For if any Body ſpeaks in ſuch a Tube, putting his Mouth in the Axis 2380.

of the Tube, and in the Forces of the Parabola, the Waves will be ſo reflected, that every one of their Parts will acquire a Motion parallel to the Axis of the Tube; by which Means the Force of the Wave, and that of the Sound too, will be very much increas'd. The greater End of the Tube, from which the Sound goes out, muſt be bent ſo as to have the Shape of one's Lips, that thereby the Wave may more eaſily be ſcatter'd every Way.

Experiment 8.

2381. Pl. 76. F. 3. Let a Perſon ſpeak in a low Voice, applying his Mouth to the ſmaller Aperture of the Tube before-mention'd; if the Tube be four Foot long, the Sound will be heard at a great Diſtance, and it will be very much increas'd in the neighbouring Places.

2382. The longer the Tube is, the more intenſe will be the Sound, and at the greater Diſtance will it be heard. There will alſo be a Difference, if, the Length continuing the ſame, the Tube be wider, like A, or narrower, like B. I have not determin'd by Experiments, through which of theſe Tubes, the Sound may be convey'd to the greater Diſtance.

SCHOLIUM I.

The Demonſtrations of N. 1150. 1152.

2383. IN order to make manifeſt, what has been ſaid concerning the Law, to which Particles, having an undulatory Motion, are ſubject, in going and coming *, we muſt conſider; that the Law of Elaſticity determines the Motion of the Air, and that, *vice verſâ*, the Law of Elaſticity may be determin'd, from that Motion being given.

* 2291.

I ſhall take this laſt Method; and ſuppoſing all the Particles, in going and coming, to be mov'd, like a Body vibrating in a Cycloid, that is, to be preſs'd with a Force, which is increas'd and diminiſh'd, with the Diſtance from the middle Point of the Space, run through in going and coming *, I ſhall demonſtrate that that very Law of Elaſticity, which we found before to obtain in Air *, is requiſite to produce this: Whence it will appear, that the Particles of the Air do really move according to the Law of a Pendulum vibrating in a Cycloid.

* 414.

* 2111.

2384. Pl. 76. F. 4. Let there be a Circle AFB, whoſe Circumference is equal to the Breadth of a Wave; let there be a ſmaller Circle, GIOL, concentric with the former, whoſe Diameter is equal to the Space, run through by the Particles, in going and coming; which as it is ſmall, this Circle is of no ſenſible Magnitude in reſpect of the other.

Let

Let us ſuppoſe the Circumference of the ſmaller Circle to repreſent the Time, in which the Wave runs through it's Breadth; that is, the Time in which a Particle goes and comes *; and therefore it runs through the Line GO twice, according to the Law of a Body mov'd in a Cycloid by Gravity: Therefore half of the Circle repreſents the Time, in which this Line is run through once. * 2284.

In the greater Circle, let EF be the Diſtance between the Centers of two neighbouring Particles at Reſt; Lines being drawn from E and F to the Center, the Arch I*i*, in the ſmaller Circle, will repreſent one of the Moments, mention'd N. 2285: For we ſuppos'd the greater Circumference to be equal to the Breadth of the Wave.

Therefore, if a Particle be carried through GH, the next Particle that follows it, which was mov'd one Moment longer, will be carried through G*h* *, IH, *ih*, being drawn Perpendicular to GO; and the Difference of their Tranſlations will be H*h*; but the Difference of the Motions of neighbouring Particles, is the Increaſe, or Diminution, of the Diſtance between them: In this Caſe, in which the antecedent Particle was carried through a leſs Space, H*h*, or I*m*, which we ſuppoſe parallel to it, is the Diminution of the Diſtancce; which itſelf is therefore EF Minus I*m*. * 467.

The Ratio between I*m* and EF is compounded of the Ratio of I*m* to I*i*, and of I*i* to EF. The firſt Ratio is that which is between IH and IC; by Reaſon of the ſimilar Right-angled Triangles I*mi*, IHC. The ſecond Ratio is that, which is between IC and CE, as is manifeſt. The Ratio compounded of theſe is that of IH to EC, or AC.

Therefore, if we denote the Diſtance between the Particles, before the Agitation, by the Semidiameter of the greater Circle, HI will repreſent the Diminution of the Diſtance, whilſt the Arch GI repreſents the Time of the Agitation *. By a like Demonſtration it appears, in the return of the Particles, that HL repreſents the Increaſe of the Diſtance, if the Arch OL repreſents the Time of the Return, that is, the Arch GIOL the Time of the Agitation. * 467.

Now if we ſuppoſe a Line PQ, parallel to GO, and which touches the greater Circle at P; and if HI be continued to R; HR will be equal to AC, taking away HI there remains IR, which denotes the Diſtance of the Particle from the neighbouring one, ſuppoſing GI to be the Time of the Agitation, if this were GIOL the Diſtance between the Particles wou'd be RL; and the Diſtances, in any Moments whatſoever, are repreſented by Lines parallel to the Line PC, terminated on one Side by the Line QPS and on the other by the Semicircle GIO in going, and OLG in coming.

The Difference between two neighbouring Diſtances is *im* or *ul*, if I*i*, or L*l*, as before, repreſents the Moment, mention'd in N. 2285. in which Caſe theſe laſt ſmall Lines are conſtant: But as we ſuppoſe the Particles to be mov'd, in going and coming, according to the Law of a Pendulum, vibrating in a Cycloid by Gravity, the ſmall Lines as *im* or *ul*, if I*i* or L*l* be conſtant, repreſent the Force accelerating the Motion,

* 468. whilſt the Time of the Agitation is repreſented by GI, or GIOL *:
2385. Therefore *the accelerating Force, which, every Moment, acts upon every one of the Particles, in the Motion which we have ſuppos'd, is proportional to the Difference between the neighbouring Diſtances of the Particles*; namely if this accelerating Force agrees with Gravity in this, *viz.* in acting upon a
* 371. Particle in Motion, as it wou'd act upon one at Reſt *; which will happen, if the accelerating Force depends upon the Elaſticity of the Air; for then the moving Cauſe is transfer'd with the Particles themſelves.

2386. But we demonſtrate that this very accelerating Force does really take Place in the Air. The Force, with which the Particles, whoſe Diſtance is repreſented by IR, mutually repel one another, is to the Force with which the Particles are repelled from one another, whoſe Diſtance is ex-
* 2111. preſſed by ir as $\frac{1}{RI}$ to $\frac{1}{ri}$ *; and the Difference of theſe Forces is the Force, with which the middle Particle is agitated; which Force is expreſſed by $\frac{1}{ri} - \frac{1}{RI} \propto \frac{RI - ri}{RI \times ri} \propto \frac{mi}{RI \times ri}$; whilſt the Force, with which the Particles at Reſt mutually fly from each other, whoſe Diſtance is repreſented GQ, is $\frac{1}{GQ}$.

Therefore theſe Forces are as $\frac{mi}{RI \times ri}$ to $\frac{1}{GQ}$, or as $mi \times GQ$ to $RI \times ri$, or to GQ^q; becauſe, as the leſs Circle is of no ſenſible Magnitude, in reſpect of the greater, QG, RI, ri, may be looked upon as equal, without any ſenſible Error. Therefore the laſt Ratio mentioned is that which is between mi and GQ; namely by dividing each Quantity by GQ, which does not alter the Ratio between them. If therefore we repreſent by GQ the Force, with which the Particles at Reſt mutually fly from one another, im, that is, the Difference of the neighbouring Diſtances, will expreſs the accelerating Force; which is that, which is required, that every one of the Particles may move according to the Law
* 2385. of a Body vibrating in a Cycloid *. Which was to be demonſtrated.

2387. The accelerating Force, which acts upon the Particles of Air, may be compared with Gravity, and the Celerity of a Wave with the Celerity of a falling Body, as was ſaid in N°. 2293.

When a Body vibrating in a Cycloid, runs through this whole Curve, it is preſſed with it's whole Weight in the Points, which are moſt remote
* 412. 458. from the middle Point of the Way to be run through *; therefore, in order to compare with Gravity the Force accelerating the Motion of the Particle, whilſt it goes and comes along GO, we ought to compare with the Weight of the Particle the Force, which acts upon it at G, or O, and preſſes it towards C.

The Lines as Ii and im are confuſed in the Point G; therefore putting AD and EF equal, that is, putting AD equal to the Diſtance between the Particles at Reſt, and drawing DC to the Center, Gg, which is equal

to

to I*i*, will expreſs the Force, which at G preſſes the Particle towards C, whilſt GQ expreſſes the Force, with which the Particles at Reſt mutually repel one another *. * 2386.

Let us ſuppoſe the Atmoſphere, whilſt the Quantity of the Air remains the ſame, to be every where above the Place, in which the Wave moves, of the ſame Denſity with the Air in this Place; and in this Caſe let the Height of the Atmoſphere be SV; let S*s* be equal to AD, the Diſtance between the Centers of two neighbouring Particles; S*s* is to SV, as Unity is to the Number of Particles in *s*V; that is, S*s* is to SV, as the Weight of one Particle to the Weight, with which the Particles S, *s*, are mutually driven towards one another; which Weight is equal to the Force, with which theſe Particles endeavour to recede mutually from one another by their Elaſticity *. * 361.

But the Weight of one Particle is to the Force at G, of which we have juſt ſpoken, in a Ratio compounded of the Weight of one Particle to the elaſtic Force of the Air at Reſt, and of this elaſtic Force to the Force at G; that is, in a Ratio compounded of that of S*s* to SV, and QG to G*g*. This laſt Ratio is compounded of the Ratio of QG, or AC, to GC, and GC to G*g*, which is the ſame as the Ratio of AC to AD or S*s*. Therefore the Ratio compounded of the Ratios of S*s* to SV, and QG to G*g*, is alſo compounded of the Ratios of S*s* to SV, AC to GC, and AC to S*s*; which is the Ratio of S*s* × AC × AC to SV × GC × S*s*, or of AC^q, to SV × GC; therefore the Force of Gravity and the Force, with which the Particles are agitated in the undulatory Motion are in this Ratio; and if a Pendulum, of the Length CG, ſhould be moved with this Force, inſtead of Gravity, it would perform two Vibrations, in the Time, in which the Wave runs through it's Breadth; for in this Time a Particle goes and comes *. * 2284.

Therefore if there be another Pendulum moved by the Force of Gravity and of the Length SV, the Square of the Time, in which this would perform two Vibrations, is to the Square of the Time, in which the Wave runs through it's Breadth, in a Ratio compounded of the direct Ratio of SV to GC, and the inverſe Ratio of AC^q to SV × GC *, of which is * 433.
compounded the Ratio of SV^q to AC^q. Therefore the Times themſelves are as SV to AC. But the Time, in which the Pendulum, whoſe Length is SV, performs two Vibrations, is equal to the Time, in which a Body, with a Celerity, acquired in falling half the Height SV, can run through the Circumference of a Circle, whoſe Semi-diameter is SV *; which * 376. 415. 470.
Time as it is to the Time, in which the Wave runs through it's Breadth, that is, the Circumference of a Circle, whoſe Semidiameter is AC, as SV is to AC, in which Ratio are the Circumferences themſelves, the Spaces run through are the Times; therefore the Velocities are equal *, and the * 120.
Propoſition delivered in N. 2293. is manifeſt.

SCHO-

SCHOLIUM II.

Of the Intenſity of Sound.

2388. WE have ſeen that the Intenſity of Sound follows the Ratio compounded, of the Ratio of the Number of Particles, ſtriking againſt the Ear, in a certain Time, and the Ratio of the Square of the * 2347. Velocity with which they ſtrike againſt it *. Theſe Ratios muſt now be determined.

The Number of Particles follows the Ratio of the Denſity of the Air; as alſo the Ratio of the Velocity of the Wave; for the ſwifter this is, the ſhorter is the Time in which the ſame Number of Particles acts upon the Ear, and the greater is the Number of the Particles acting at the ſame Time. The Number of theſe Particles alſo follows the Ratio of the Space, run through by the Particles in going and coming; for the greater the Space is, the more the Particles remote from the Drum of the Ear run againſt it. Laſtly this Number follows the inverſe Ratio of the Breadth of the Wave; becauſe the Percuſſions of the ſame Particles are the leſs frequent, the broader the Waves are.

The Square of the Velocity, with which all the Particles act, follows the Ratio of the Square of the Velocity of the Wave. Of the Square of the Space run through, in going and coming. Laſtly the inverſe Ratio of the Square of the Breadth of the Wave.

2389. *When the Velocity of the Wave is not changed, the inverſe Ratio of the Breadth of the Wave is the direct Ratio of the Number of Waves, running againſt the Ear in a determinate Time*; ſuppoſing equal Waves to follow one another, ſuch as are the Waves, which are generated by the continued Agitation of a Fibre.

The Ratio compounded of all the Ratios mentioned is the Ratio compounded of the Ratio of the Denſity, the Ratio of the Cube of the Velocity, the Ratio of the Cube of the Space run through in going and coming, and the inverſe Ratio of the Cube of the Breadth of the Wave.

If we ſet aſide the Acceleration mentioned in N. 2305. (which does not alter the Velocity with which every one of the Particles is moved, which only is treated of here.) The Cube of the Velocity follows the ſeſquiplicate direct Ratio of the Elaſticity and the ſeſquiplicate inverſe Ratio of the * 2298. Denſity *.

Therefore the two firſt Ratios mentioned are reduced to the ſeſquiplicate Ratio of the Elaſticity, and the Inverſe ſubduplicate Ratio of the Denſity. * 361. But the Elaſticity is as the compreſſing Weight *, which follows the Ratio of the Height of the Mercury in the *Torricellian* Tube.

2390. Therefore *in general, the Intenſity of Sound is directly as the Square Root of the Cube of the Height of the Mercury in the* Torricellian *Tube, as the Cube of the Space run through in going and coming, and as the Cube of the Number of Waves, running againſt the Ear in a determinate Time, and inverſely as the Square Root of the Denſity.*

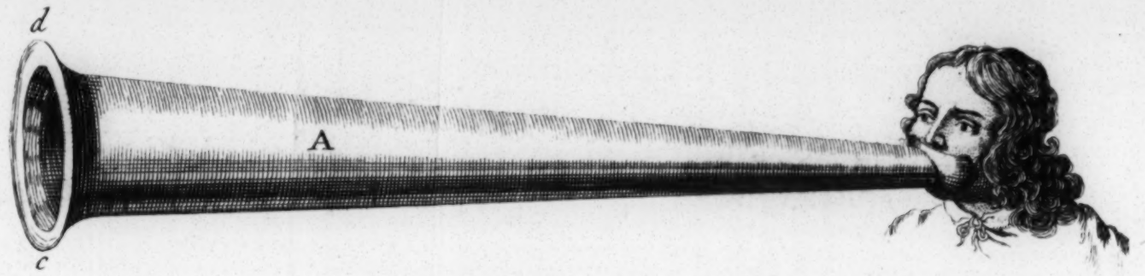


Fig. 3.



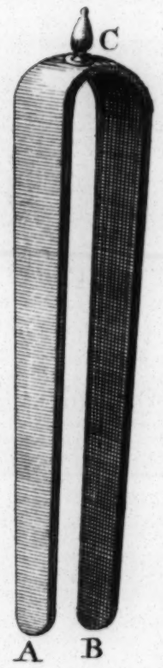


Fig. 1.

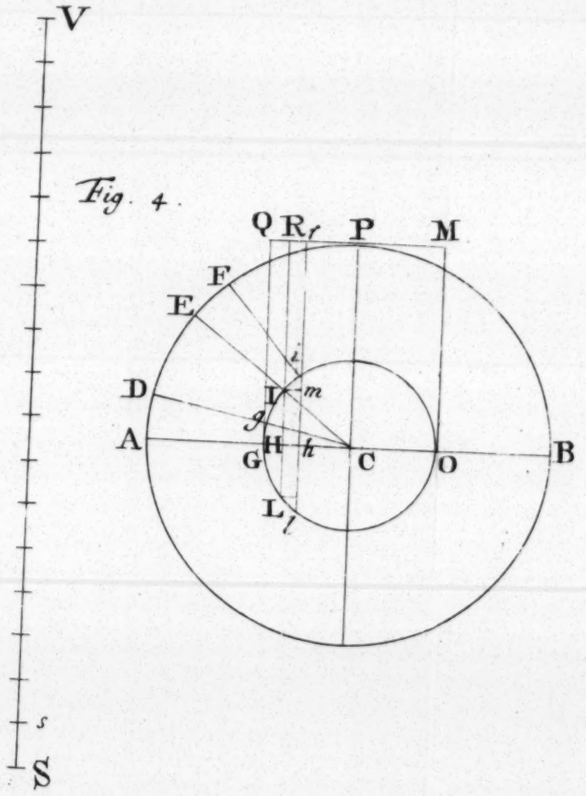


Fig. 4.

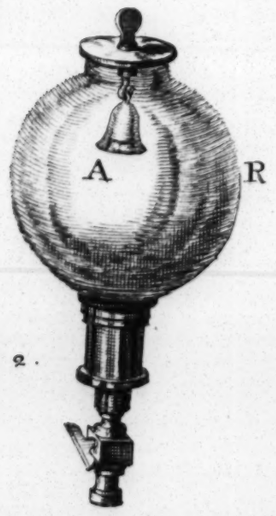


Fig. 2.

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BOOK V.

PART II. Of FIRE.

CHAP. VIII.

Of the Properties of Fire in general.

THE Philoſophers know a few Properties of Fire, yet many Things relating to it are conceal'd from them. I ſhall not invent Hypotheſes, but ſhall lay together, in as good Order as I can, ſuch general Things about it as appear to me to be deduc'd from Experiments. 2391.

The intimate Nature of Fire is unknown; but *wherever we find Heat and Light*, we ſay that there is what we call Fire. 2392. 2393.

Therefore in order to inquire into the Properties of Fire, we muſt examine ſuch Bodies wherein *we diſcover* one or the other of theſe *Tokens of the Preſence of Fire*.

For we do not every where find both theſe together; in ſeveral hot Bodies we can perceive no Light; neither in ſeveral light Bodies can we diſcover any Heat. But whether there be really ſuch a Separation, we ſhall examine hereafter *. 2394. * 2418.

We ſhall alſo ſee, though perhaps it cannot be fully demonſtrated, *that Heat and Light proceed from the ſame Cauſe*, which, notwithſtanding, there is *no Body can doubt*. 2395.

Fire penetrates into all Bodies, however denſe and hard; at the ſame Time alſo Heat is communicated into their inward Parts. 2396.

Fire unites itſelf to Bodies; for that which ſtays in the Surface, is alſo transfer'd with the Bodies. 2397.

We ſhall ſee alſo that *Fire is attracted by Bodies at a certain Diſtance*. 2398.

Moreover, *we have no Knowledge of any Bodies but what contain Fire in them*. 2399.

Yet *Fire does not enter into all Bodies with the ſame Eaſe*; which is to be attributed to ſeveral Cauſes, not known. It appears by Experiments 2400.

Experiments that when the Denſity is increas'd the Heat is diminiſh'd, and the Ingreſs becomes more difficult.

2401. *The Fire contain'd within Bodies, is kept there by the Bodies that ſurround them.*

2402. That *Fire* moves appears from what we now demonſtrate, and that *it's Motion is exceeding ſwift*, is manifeſt from that moſt violent Agitation which is caus'd in Bodies, by the Action of Fire.

2403. When the Heat *of Bodies* is increas'd, *the Bulk of them is increas'd* too; and therefore they are dilated or ſwell'd *by the Action of Fire*. But upon the Increaſe of the Dilatation there are often
2404. Parts ſeparated from the *Bodies*, which mutually repelling one another by the Action of the Fire, *form an elaſtick Fluid*, into which whole Bodies are *oftentimes* turn'd *by the Action of Fire*.

2405. But if this Motion in Bodies, by which they are dilated, be increas'd, the Effect of it is chang'd; and the Parts of the fluid Bodies, not yet ſeparated, are ſenſibly agitated with a very violent Motion; and the Parts of the ſolid Bodies, which are not ſo ſubtile, will be ſeparated from the adjacent ones.

2406. Which Motions nevertheleſs are often to be attributed to the Action of ſubtile Particles moved by the Fire, and penetrating the Pores of the Bodies.

2407. For that *there are ſubtile Parts, diſtinct from Fire, which penetrate Bodies by the Action of Fire*, is evident from the Increaſe of the Weight of ſome Bodies by the Action of Fire: Since *Fire*
2408. itſelf *has no ſenſible Weight*.

CHAP. IX.

Some general Things concerning Heat and Light.

* 2393. WE have already obſerv'd * that Heat and Light are the Tokens of the Preſence of Fire; we ſhall therefore often ſpeak of them, and general Things relating to them muſt be taken Notice of firſt of all.

2409. *The Heat in a Body muſt be diſtinguiſhed from the Heat which we feel*; for that is the Action of the Fire upon the Body, which is ſaid to be hot, from whence the Parts of the Body receive a certain Motion, by which a Motion is communicated to ſome Parts of our Body, which is united with the Perception of the Heat.

But *Heat, with regard to us, is nothing elſe but that Perception*; and all that is in the hot Body, is only the Motion ariſing from the Action of the Fire. 2410.

The Light which ariſes from Bodies moves in right Lines, and thoſe Bodies from which it ariſes are call'd lucid Bodies. 2411.

When Light enters into our Eyes, it moves the ſmall Fibres at the Bottom of the Eye; by which Motion the Perception of Light is produc'd in our Mind; and this Perception with regard to us is Light; but in regard to Bodies, Light is that which they emit into our Eyes. 2412.

What has been obſerv'd in general concerning the Senſations *, muſt alſo be refer'd to Heat and Light. 2413. * 2310.

That the Motion of Light is in right Lines, appears from it's being ſtopp'd by an Obſtacle. 2414.

But that *ſuch a Motion is not requir'd in Heat, and* that *the Fire which is mov'd in different Lines excites a greater Heat*, appears from the Augmentation of this, whilſt the Parts of Bodies are ſubject to different Motions. 2415.

All hot Bodies do not ſhine, as we daily obſerve; but we cannot conclude from thence that they have no Light. For very often a ſmall Light, which we do not perceive, will be very ſenſible to other People; this depending upon the Conſtitution of the Eyes. From whence it follows, that there may be Light, though not perceiv'd, becauſe of the too ſmall Quantity which the lucid Body emits. 2416.

In like Manner the Heat in a Body may be ſo leſſen'd, as to be imperceptible to us; for it often happens that a ſmall Heat, which does not at all affect us at one Time, will do ſo very ſenſibly at another Time: And therefore we cannot affirm that no Heat is in lucid Bodies, becauſe we do not obſerve any. 2417.

Therefore *it is uncertain whether Heat and Light can ever be ſeparated.* 2418.

But that theſe are very often united, there is no Body doubts. But whether both Heat and Light are juſtly ſaid to be the Tokens of the Preſence of Fire, that is, whether we can aſcribe to the ſame Cauſe theſe two different Phenomena, ſo as to entirely remove all Scruples, cannot be determin'd; yet, notwithſtanding, the two following Conſiderations ſeem to ſhew that there is a Poſſibility of determining this Queſtion. 2419.

In the firſt Place, there are *many hot Bodies, which, when their Heat is encreas'd, do emit Light*; and to do this there is only requir'd an 2420.

increaſe of the Heat; and upon the leſſening of this the Light ceaſes. Red hot Iron emits Light, but when the Heat is diminiſh'd no Light can be perceiv'd. Smoak, as we ſhall ſee preſently, is turn'd into Flame, when it's Heat is increas'd.

2421. Secondly, *In the Sun's Rays there is a very intimate Union between the Heat and Light.* Thoſe Bodies which reflect a great Quantity of Light, grow hot but ſlowly; but thoſe which a greater Quantity of Light penetrates into, acquire Heat faſter; and whilſt the Light penetrates the Body, it does not always communicate to it a ſenſible Light together with the Heat, which yet often happens.

2422. Many calcin'd Stones, after they have been expos'd to the Sun's Light, ſhine in the dark, which Light continually decreaſes, and at laſt diſappears; but it is reſtor'd again by a new Action of the Sun's Rays, and that ſeveral Times. Which ſame Property has been obſerv'd in other Stones, without any Preparation; not only when they have been expos'd directly to the Rays of the Sun, but if they have only been for ſome Time expos'd to the Light of the Day, in a Place, to which the Sun's Rays do not come directly.

In all theſe the Light is not communicated without Heat; and in the Caſes in which this is weak, the Light communicated is alſo weak; but in other Caſes Bodies acquire Heat, without any ſenſible Light, by the ſame Action of the Sun's Light, let this be ever ſo vivid.

2423. But *in the Moon's Light*, which proceeds from the Sun, *there cannot by any Art be diſcover'd any Heat*; yet there is nothing to be
2424. gather'd from thence that Light and Heat are diſtinct. *The Sun's Light, reflected by the Moon, which comes to us*, is very weak.

When the Moon is view'd with a Teleſcope, ſome Particles appear more lucid than the reſt of the Surface; but all thoſe join'd make but a ſmall Portion of the Surface illuſtrated. Theſe more lucid Particles do *not* reflect all the Light, which comes to them; whence it appears that the Light, reflected from the other Parts of the Surface of the Moon, is very much diminiſh'd. If to this we add that a great Part of the Surface of the Moon appears obſcure, it will be manifeſt, that the Moon reflects only a ſmall Part of the Light, which comes to it from the Sun. This Light, thus already weaken'd, is diſpers'd before it reaches us, whereby it is again diminiſh'd almoſt fifty thouſand Times. Yet this very Light is perceiv'd by the wonderful Structure of our Eyes; if the Heat were leſſen'd ſo much, who wou'd affirm that it ever *can produce any ſenſible Effect?*

CHAP.

CHAP. X.

Of the Dilatation ariſing from Heat.

WE have already ſaid that Bodies are dilated by Heat * ; but as this *Dilatation* always increaſes with the Heat, and this being leſſened, is leſſen'd, it *forms a new Token of the Preſence of Fire*, which is more certain than thoſe mention'd before * ; for we can meaſure the Dilatation, when at the ſame Time the various Perceptions of Light, or Heat, can ſcarcely be compar'd together. * 2403. * 2425. * 2393.

It is evident, by Experiments, that Bodies are dilated by Heat. 2426.

EXPERIMENT 1.

The Aperture of the Copper Ring AB is circular, and it's Diameter is an Inch and an half; and this is the Diameter of the ſolid Ball G, which is made of the ſame Metal; this can paſs through the Aperture, without leaving any ſenſible Interſtice. When the Globe is heated it is ſuſtained by the Ring, in whatever Poſition it is laid; which Experiment alone ſhews that Bodies dilate every Way. 2427. Pl.77.F.1.

It may be obſerv'd daily, that *Fluids are dilated by Heat, in the ſame Manner as Solids*, in Thermometers, which are well known Inſtruments, made of Glaſs. 2428.

Two ſuch Inſtruments are repreſented at AG, and DC; they are made of a Ball G, or better of a Cylinder C, with a Tube join'd to it, as AB, or DE; they are fill'd with tinged Spirit of Wine, or ſome other Fluid, which does not loſe it's Fluidity by Means of Cold. Pl.77.F.2.

EXPERIMENT 2.

A ſmall Heat, communicated to the Ball, cauſes a ſenſible Expanſion in the Tube. 2429.

If we make Uſe of Mercury, the denſeſt of Fluids, the Dilatation is more regular; but the Tube muſt be narrower, becauſe this Fluid dilates leſs. 2430.

Theſe Inſtruments are applied to Frames, and the Dilatations are compar'd, by Means of Diviſions diſpos'd along the Tube. 2431.

But it is uncertain, whether theſe Inſtruments can ſhew the Degree of Heat, although they ſhew the ſmalleſt Alterations of Heat. That 2432.

is, the Relation between the Alteration in the Expanſion and the Alteration in the Heat, is not enough known, that the Degrees of Heat may be compar'd together, from comparing the Dilatations.

2433. If the Ball G becomes hot on a ſudden, or the Cylinder C, the Fluid immediately deſcends in the Tube; but it aſcends immediately after.

Experiment 3.

2434. Boiling Water is pour'd into the Veſſel V; the Ball G of the Pl.77.F.3. Thermometer is immediately immerg'd into it; and the Fluid that very Moment deſcends from *c* to *d*; but it immediately returns to *e* and higher: Then if the Ball be not ſuddenly taken out of the Water, the Spirit of Wine will riſe to the Top of the Tube, and break the Glaſs by it's greater Expanſion.

2435. The Reaſon of this Phenomenon is as follows.

By the ſudden Heat, applied to the Glaſs, it is dilated, before the Heat penetrates into the Fluid contain'd in the Glaſs; therefore, the Fluid deſcends by Reaſon of the Increaſe of the Capacity of the Glaſs; but the Heat is immediately communicated to the Fluid; which therefore aſcends.

2436. From the Expanſion of Bodies it is evident, that *the Particles, of which Bodies conſiſt, acquire a repellent Force from the Action of Fire, by which they endeavour to recede from one another*, and which acts contrary to that Force by which the Particles come towards
* 72. each other *. So long as this laſt Force exceeds the other, the Particles cohere more or leſs, according to the different Degree of Heat. When the repellent Force is nearly equal to the attractive Force, the Particles, which were before intimately join'd, ſcarcely cohere, yield to any Impreſſion, and are eaſily mov'd one amongſt another, if this be not prevented by another Cauſe; in this Caſe *a*
2437. *ſolid Body is chang'd into a Fluid by Heat*; which we may obſerve of all Bodies that are melted by Heat, and return to their firſt State when the Heat is diminiſh'd.

2438. *It is a Queſtion whether all Fluidity is not owing to Heat?* But *this cannot be determin'd*; becauſe we know of no Body that is entirely without Fire in it. This is certain, that Heat is not only the Cauſe of the Fluidity in melted Metals, Wax, and ſuch like Bodies; but ſeveral Bodies, which are commonly reckon'd amongſt
2439. Fluids, proceed only from Heat: Thus *Water is melted Ice*; for when Part of the Heat of the Water is gone, it grows fixed.

Heat

Heat may be ſo increas'd, that in ſome Bodies the whole attracting Force of the Particles may be overcome by the repellent Force; in which Caſe the Particles fly from each other; that is, they acquire an elaſtick Force, which is like that, which the Particles of Air have *; (which alſo is increas'd in the Air by Heat;) we obſerve this Effect in Smoke and Vapours. 2440. * 2096.

EXPERIMENT 4.

Take an hollow Braſs Ball E, of about four Inches Diameter, with an Handle M; this Ball has a Pipe T with a Hole of hardly the twentieth Part of an Inch. Let this Ball be heated, and the Air in it will expand itſelf *, and come out through the Pipe; then, immerging the Ball in cold Water, the Air will be again condenſed by the Cold, and the Water will go into the Ball, by the Preſſure of the Atmoſphere upon it's Surface. 2441. Pl.77.F.4. * 2428.

If this Ball, thus partly fill'd with Water, be laid upon the Fire, the Moment that the Water is chang'd into Vapours, thoſe Vapours will go out through T; but if the Heat be increas'd, ſo as to make the Water boil violently, the Vapours, compreſs'd in the upper Part of the Ball, will, by their Elaſticity, endeavour to recede from each other every Way, and ruſh violently out of the Pipe. 2442.

Such an Inſtrument is call'd an *Æolipile*. 2443.

The following Experiment ſhews a more ſenſible Effect of the Elaſticity of Vapours.

EXPERIMENT 5.

Take the Ball E, which is alſo of four Inches Diameter, made thicker than the Ball, made Uſe of in the foregoing Experiment, and let it be join'd to Rollers or little Wheels, as is repreſented in the Figure. In it's upper Part a ſquare Box T, open forwards at *a*, is join'd to it. In the Middle of this Box there is a Separation, and the hind Cavity communicates with the Cavity of the Ball. This Separation has a Hole in the Middle of it of about $\frac{1}{8}$ of an Inch Diameter. This Hole is ſtopt up with a Copper Pin, which goes through two Holes, as L, in the Sides of the Box, and applies itſelf to the abovemention'd Separation, and as the Figure of the Pin is ſomewhat conical, if it be drove in with a Hammer, it will exactly ſtop the Hole. 2444. Pl.17.F.3.

Take this Ball off of the Rollers or little Wheels; then let it be heated, and in Part fill'd with Water, as in the foregoing Experiment. Let the Ball be again put upon the Fire, 'till the Water 2445.

boils, then ſhut the Hole, and let the Ball remain upon the Fire a little while, that the Vapour may be accumulated. Now join the Ball to the Wheels, and open the Hole, and the Vapour will fly out violently one Way, whilſt the Ball is carried the contrary Way.

2446. The Vapour, being very ſtrongly compreſs'd, endeavours to recede equally every Way, and therefore oppoſite Preſſures deſtroy one another; but when the Hole is open'd, the Vapour, which goes out, does not preſs; therefore the Preſſure one Way being taken off, that which acts in a contrary Direction prevails, and the Ball is mov'd along.

2447. A Sky-Rocket riſes up into the Air, becauſe the Gun-powder, being ſet on Fire, is turn'd into an elaſtic Fluid, and it's Parts endeavour to recede every Way: As the Pipe, or Caſe of it is open at one End, it is leſs preſs'd that Way, and conſequently at the other End, the Preſſure prevails, and carries up the Rocket.

2448. *To the* ſame *Action of Fire*, whereby Parts are ſeparated by Means of Dilatation, *we may alſo refer the* Separation of Parts, which conſtitute *the elaſtic Fluid, proceeding from Bodies, by Means* * 2119. *of Putrefaction, Fermentation, and Effervеſcence* *. For this Separation is always accompanied with Increaſe of Heat, even in cold Effervеſcences themſelves.

Experiment 6.

2449. To twelve Parts of Water add one Part of Oil of Vitriol; this Mixture acquires Heat, which laſts but a little while; then pour Pl. 77. Fig. 5. it into the Glaſs V, which is laid upon the Plate G of the Air-pump.

* 2152. To the ſame Plate we apply the ſmall Braſs Plate AB, which we faſten to the ſmall Pipe, through which the Air is exhauſted *, whoſe Screw goes through a Hole at B.

To this Plate is join'd the Cylinder C, which ſuſtains another Plate L, which is alſo of Copper, and is ſo bent, as to be ſurrounded on one Side with a Groove *i*, making a Portion of a Circle, whoſe Center is in the Middle of the Hole *h*; this Groove is clos'd behind, as appears at *q*, and is fill'd with Sal Ammoniack, reduc'd to a Powder.

The Thermometer D is put into the Glaſs; this, together with it's Paper Scale, which is join'd to it, is inclos'd in a Glaſs Tube, and repreſented diſtinctly in Fig. 3. Pl. 81; there is alſo another Thermometer E made uſe of, which has a Stand. All theſe are cover'd with the Receiver R, which is clos'd with the Cover O.

To

To the Cover is join'd the Collar of Leathers P *, whoſe Braſs Wire * 2155.
st, or ST, goes through the Hole *h*, and fits it exactly. To the ſame Wire is join'd the Plate F, whoſe Part *n*, when the Wire is puſh'd down, reaches to the Bottom of the Groove. But the Wire is ſo diſpoſs'd, that if, by turning the Handle, the Plate F be agitated, it will not touch the Sal Ammoniack, which fills the Groove; but by depreſſing M, the Prominence *n* ſeparates a Part of the Sal Ammoniack in the fore Part of the Groove from the reſt.

The Air is exhauſted from the Receiver R, and by turning the 2450.
Handle M, the Sal Ammoniack, in the fore Part of the Groove, is thrown into the Glaſs V. There is immediately caus'd a great Efferveſcence, which is increas'd, by ſeparating ſome more Sal Ammoniack in the Groove, and throwing it into the Glaſs again in the ſame Manner as before.

During this Efferveſcence the following Obſervations are to be 2451.
made; 1. That the Mercury in the Thermometer D is depreſs'd; whence it appears that the Efferveſcence is cold, though moſt of them are hot. 2. That the Mercury in the mercurial Gage of the Air-pump deſcends; which demonſtrates the Generation of an elaſtic Fluid. 3. Laſtly that we diſcover by the Thermometer E, in which the Murcury aſcends, that the Separation of Parts is made with Heat.

We make the Experiments in a Vacuum, that the Phenomena may be the more ſenſible.

CHAP. XI.

Of the Fire contain'd in Bodies, where we ſhall ſpeak of Electricity.

WE have already ſaid that Fire is contain'd in all Bodies 2452.
known to us *. And this we find to be ſo, becauſe we * 2399.
every where find Fire; for there are no ſolid Bodies round the whole Surface of the Earth, but what may be made hot by rubbing; but what is demonſtrated in the following Chapter, does more evidently prove, that there is Fire every where throughout the Surface of the Earth; *viz.* that Heat is communicated from a Body which is hot, to another near it, which has not ſo much Heat: From whence it follows, that if there be any without Fire, and ſo without Heat, it will immediately receive Heat from the neighbouring Bodies.

There are ſeveral very remarkable Phenomena, which are aſcrib'd to the Fire contain'd in Bodies; ſome of which ought to be mention'd here: Amongſt which there are ſuch as have a near Relation to Electricity; for which Reaſon we muſt alſo treat of the Phenomena of Electricity.

Definition.

2453. *Electricity is that Property of Bodies, by which when they are heated by Attrition, they attract and repel light Bodies at a ſenſible Diſtance.*

2454. Many Philoſophers thought that very few Bodies had this Property; but it is now manifeſt that moſt Bodies have it, though unequally, and in a different Manner. Many ſurpriſing Things concerning this Property have been diſcovered in *England* and *France*; but to treat of this Matter wou'd lead us from our Purpoſe; I ſhall only mention a few Experiments, made above thirty Years ago in *England*, to make manifeſt the Connexion between the Cauſe of Electricity and Fire, if theſe two ought really to be diſtinguiſh'd; later Experiments confirm my Concluſions.

Experiment 1.

2455. A Glaſs Tube 15 or 18 Inches long, and of above one Inch in Diameter is rubb'd with a dry Hand, or with a dry linen cloth, and Light is perceiv'd; this follows the Hand, and does not remain in the Tube itſelf, but, at a ſmall Diſtance from it, in the Body, with which the Tube is rubb'd.

2456. When we ceaſe to rub the Tube no Light is perceiv'd; but, if any Body be mov'd along the Tube a ſmall Diſtance from it, not exceeding a Quarter of an Inch, a faint Noiſe is heard, and ſparks of Fire emitted as it were out of the Glaſs with a Noiſe, appear upon the Surface of this Body. If the Body be again carried along the Tube, nothing of this is obſerv'd, without the Tube is firſt rubb'd again.

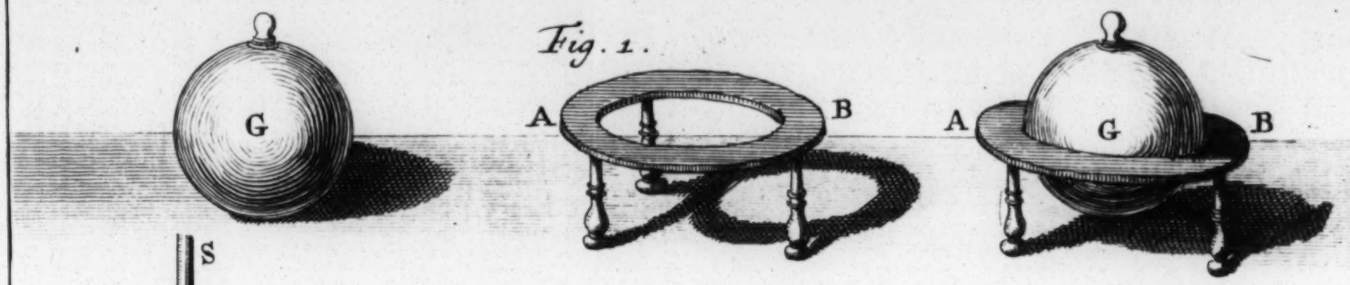
Experiment 2.

2457. This Tube by being rubb'd, acquires a very ſenſible Electricity; for if light Bodies, ſuch as Leaf Gold and Soot, be laid upon a Plane, and the Tube be brought near to them, they will be put in Motion, attracted, and repell'd, and driven ſeveral Ways by the Tube.

Pl. 78. Fig. 2.

If

Fig. 1.



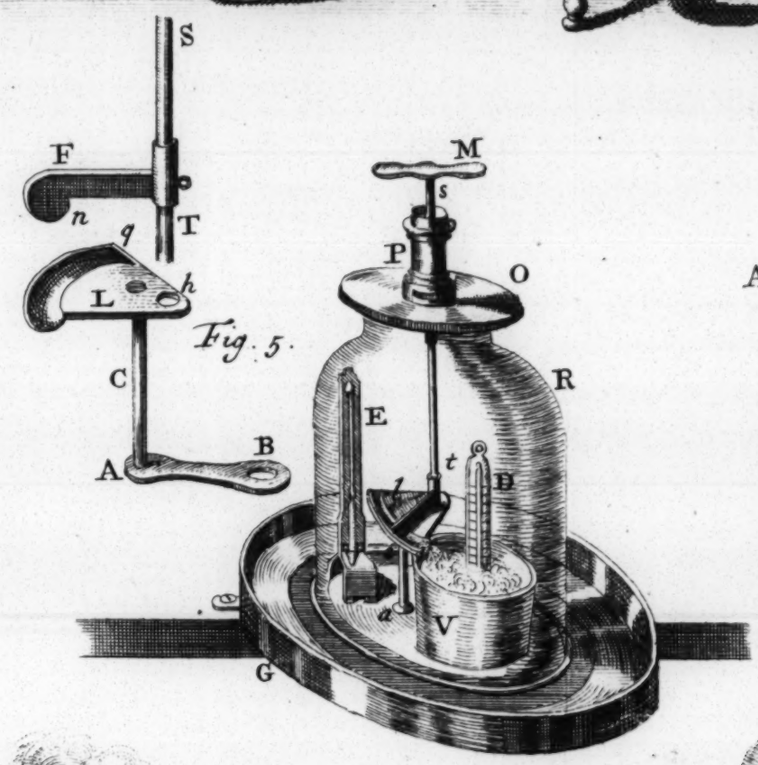


Fig. 5.

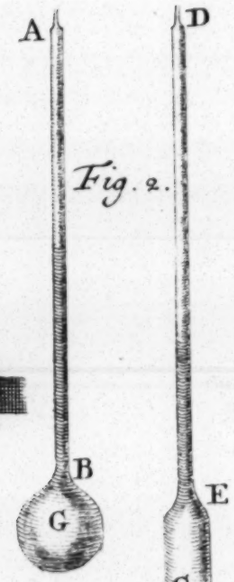


Fig. 2.



Fig. 3.

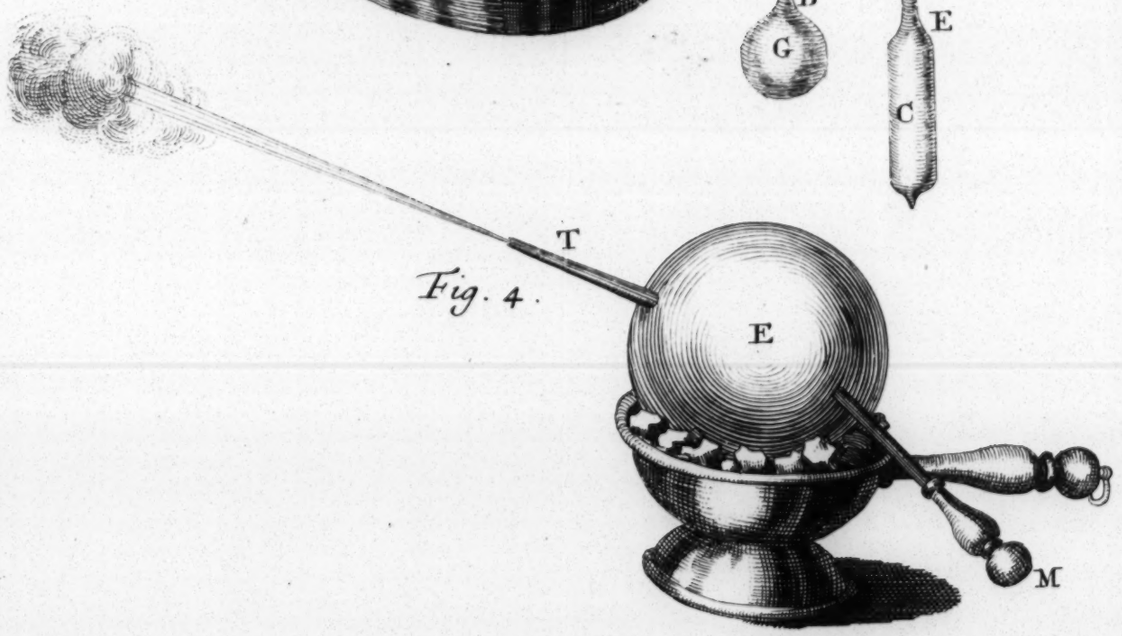


Fig. 4.

T. Mynde sc.

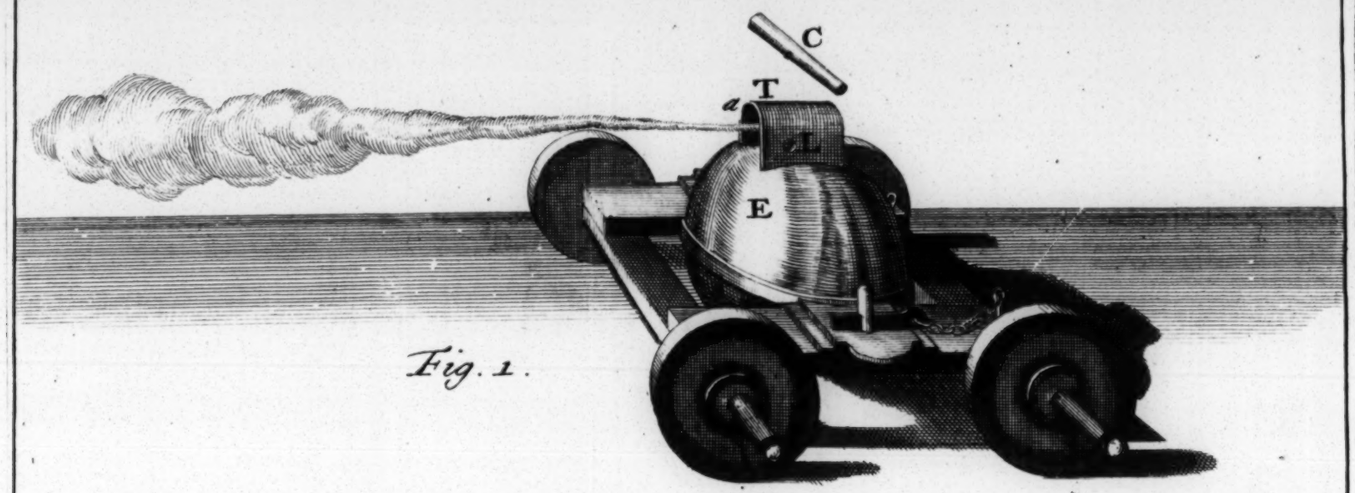


Fig. 1.

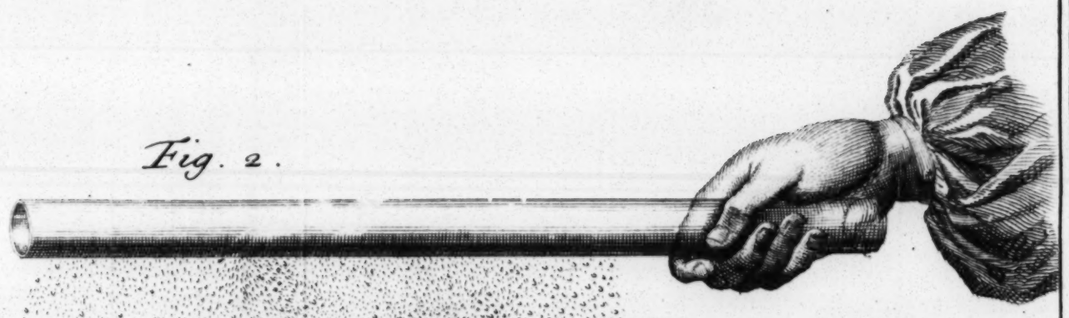
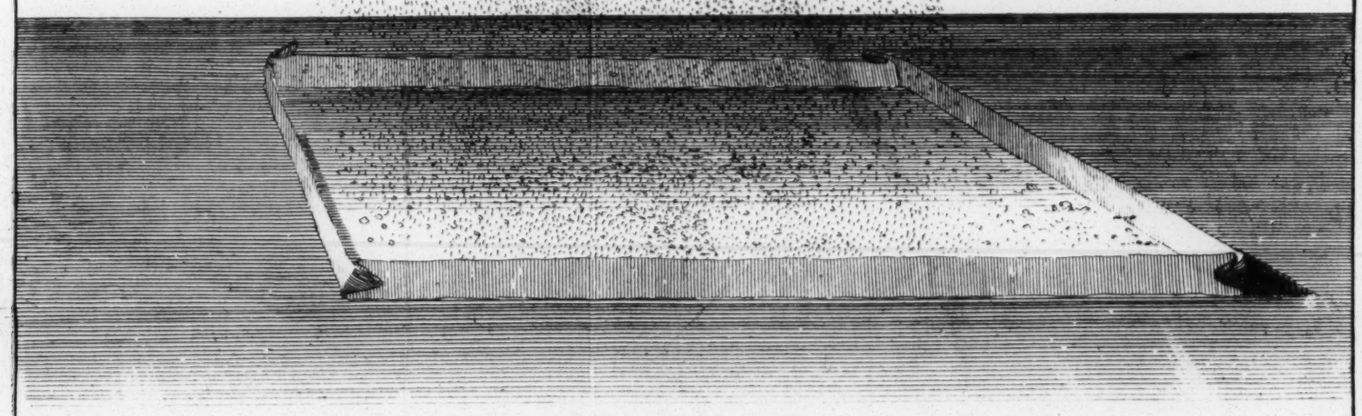


Fig. 2.



J. Mynde sc.

If a Body, at a ſmall Diſtance from the Tube, be mov'd along it, a Noiſe is heard, as in the foregoing Experiment, and the Electricity ceaſes, which is reſtor'd again by Friction. 2458.

A MACHINE,

Whereby Glaſs Globes are ſwiftly whirl'd about.

In the following Experiments Glaſs Globes are ſwiftly whirl'd about. Such a Globe is repreſented at G; the two oppoſite Parts of it are cylindrical; one of which is open, and both theſe Prominences are ſurrounded with the Copper Ferrels *a* and *b*. A Cock *e* muſt be ſcrew'd on to the Ferrel at the open Part of the Globe; and the oppoſite Braſs Cylinder muſt have a little Wheel *r*, of about two Inches Diameter, join'd to it, with a ſmall Braſs Axis ſtanding out; there is juſt ſuch another Piece of Braſs ſcrew'd on to the Cock, ſo that it may be taken on and off at pleaſure. Theſe Axes go into the Pillars ST, that ſupport the Globe, and which have the Holes *c*, *c*, in them, to receive the Axes, upon which the Globe turns. 2459. Pl. 79 F. 1.

The Pillars ST ſtand upon a ſtrong horizontal Board, at leaſt an Inch and an half thick, framed into three other Boards E, F, I. Between the foremoſt is ſuſpended the Wheel R, which is turn'd round by the Handle M. Between F and I is plac'd the croſs Piece H, to make the Machine the firmer. 2460.

The Pillar S may be faſtened in either of the three Places, *i*, *i*, *i*; the Tail of it, which has a Screw upon it, goes through the Board, that an outward Screw, which is ſcrew'd on by a Key, may be join'd to it under the Board, a thin Plate of Iron being firſt put between, that the Wood may receive no Damage; which that it may be done conveniently, the Board E is cut at *l*, *l*, *l*. In the ſame Manner, the other Pillar T, which moves in a Slit, is faſtened under the Board, by Means of a Screw; for this Motion is neceſſary, when the Globe is to be applied to the Machine or remov'd from it. This Slit is four or five Inches long; becauſe the Globes, which we make Uſe of in the Experiments, are not all equal. There muſt be three ſuch Slits, to anſwer to the Holes, *i*, *i*, *i*. 2461.

By the Wheel R the Globe G is ſwiftly whirl'd about; becauſe the Rope, which goes round the Wheel R, goes alſo about the ſmall Wheel *r*.

2462. At the Side of the Board D, there is a Slit at *n*, along which the Pulley *t* moves, as is repreſented ſeparately at N; this Pulley coheres with the Screw *d*, by Means of which it is mov'd along the Slit, whereby the Rope is ſtretched that goes about the Wheels R and *r*, which Rope alſo goes about a Pulley fix'd under the Board, as is repreſented at M, the fix'd Pulley is *q*.

Experiment 3.

2463. Apply a Glaſs Globe of about eight or nine Inches Diameter, to
Pl.79 F.2. the Machine above-mention'd, and let it be briſkly whirl'd in a dark Place, the Hand all the while being held againſt it, to give it Attrition.

If the Globe be exhauſted of it's Air, it will appear all luminous within, but moſtly ſo where the Hand touches the Glaſs.

Experiment 4.

2464. But if the Globe has Air in it, and being whirl'd in the ſame Manner, the Hand be applied to it, no Light appears, either in the inner or outer Surface of the Glaſs; but Bodies at a ſmall Diſtance from the Glaſs (as for Example at a Quarter of an Inch, or nearer) become luminous; and ſo only thoſe Parts of the Hand held againſt the Glaſs, which terminate, or rather environ the Parts that immediately touch the Globe, are luminous, as was ſaid
* 2455. of the Tube *.

Experiment 5.

2465. We make Uſe of four Iron Pillars, ſuch as we have mention'd *;
Pl.79.F.3. two of them are faſtened in the ſide Holes *i*, *i*; the two others in
* 2460.2461. the correſponding Slits. The two Glaſs Globes G, and H, are applied to the Board, which are turned about by one Rope only, but it is longer than that which was uſed in the foregoing Experiments. The Globe H has Air in it, G is exhauſted; the ſmalleſt Diſtance between the Globes, is equal to a Quarter of an Inch. The Globes being whirl'd about in the Dark, if the Hand be applied to the Globe H, and there is a Friction, the other Globe G becomes lucid, and the Light is of the Figure, repreſented here. If the Motion of the laſt Globe be directed towards the contrary Part, the Figure of the Light is turned the other Way; but it remains, whether the Motions of both Globes conſpire, or are contrary.

When

When the Friction is left off, but the Motion is continued, it often happens, that the Light continues ſome Time, before it diſappears.

Experiment 6.

We make uſe of the ſame Globe alſo here, which we uſed in the third and fourth Experiments; and it is applied to the Machine in the ſame Manner, that it may be whirl'd about: The upper Part of the Globe is ſurrounded, at the Diſtance of about four Inches from the Globe, with a Braſs Wire *mpo*, circularly bent in the upper Part, and whoſe Ends are faſtened in the Board. Small Threads are tied to it, which being extended towards the Center of the Globe, come within a Quarter of an Inch of the Surface of the Globe. 2466. Pl.79.F.1.

Whirl the Globe and apply the Hand, and immediately the Threads will be mov'd irregularly by the Agitation of the Air; but when the Glaſs is heated by the Attrition, all the Threads are directed towards the Center of the Globe, as may be ſeen in the Figure: And if the Hand be applied a little on one Side, the Threads will be directed obliquely to another Point in the Axis.

Experiment 7.

If the Air be drawn out of the Globe this Effect ceaſes. 2467.

Experiment 8.

Take another Globe different from that, with which the foregoing Experiments were made. In this Experiment the Aperture of the Globe G muſt be larger; that you may put into it a round flat Piece of Wood *o*, that has a Braſs Wire *q* joined to it. In order to fix this Piece of Wood in the Middle of the Globe, the Wire is ſcrew'd on to the Cover, which is applied at *h* to the Aperture of the Globe, the Cock *e* is joined to the Middle of the Cover. 2468. Pl.79.F.4.

To the Circumference of the Wooden Circle *o* ſmall Threads are faſten'd, which, being extended, almoſt touch the inner Surface of the Globe.

Apply the Globe to the Machine before-mention'd *, and turn it round; and rub it, as was done in the former Experiments: The Globe being heated by the Friction, if you ceaſe to whirl the Globe, and the Hand be taken off, the Threads will immediately ſtretch themſelves out like Radii from the Center towards the Surface of the Globe; yet they hardly remain one Moment at Reſt, * 2459.

and though the Globe be exactly ſhut, theſe Threads are put in Motion by the Agitation of the outward Air, as appears by blowing againſt the Globe, though you ſtand two Foot off, or farther, from the Globe. If you bring your Finger towards the Globe, though you do not touch it, the Threads next to it will be attracted by the Finger, and directed towards it; nay, and ſometimes they fly from it. If you apply the Hand to the Globe, the Threads will be mov'd violently and irregularly.

EXPERIMENT 9.

2469. And if the Air be drawn out, as in the foregoing Experiment, the Effect ceaſes, and the Threads (both before and after the Friction) only hang down by their Gravity. If only Part of the Air be taken out, the Erection of the Threads, and their Agitation, take Place.

2470. If we attend to all the foregoing Experiments, the following Concluſions ſeem to be naturally deduc'd from them, which we do not give out as certain, but very probable; for we muſt always diſtinguiſh Certainty from Probability.

2471. *That Glaſs contains in it, and has, about it's Surface, a certain*
* 2457. 2466. *Atmoſphere, which is excited by Friction* *, *and put into a vibratory*
2468. *Motion*; for it attracts and repels light Bodies †. The ſmalleſt
† 2457. Parts of the Glaſs are agitated by the Attrition, and by Reaſon of their Elaſticity, their Motion is vibratory, which is communicated to the Atmoſphere above-mentioned; and therefore that Atmoſphere exerts it's Action the further, the greater Agitation the Parts of the Glaſs receive when a greater Attrition is given to the Glaſs.

The Action of this Atmoſphere produces other Effects alſo; for to the Friction alone, ariſing from this Action, we ought to attribute the Light, which appear'd in the exhauſted Globe, in the
* 2465. fifth Experiment *, there being no viſible Friction.

2472. *The Fire, contain'd in the Glaſs, is expell'd by the Action of this Atmoſphere*, at leaſt it is mov'd with it. For when light Bodies are put in Motion at a Diſtance from the Glaſs; the Bodies alſo become
* 2455. 2457. 2466. 2464. lucid at a Diſtance *.

2473. It is plain, that *this Atmoſphere and Fire is more eaſily mov'd in a Place void of Air:* For if the Globe be exhauſted of it's Air, there can be perceiv'd no Light, nor any Action of Electricity on
* 2463. 2467. the Outſide of the Globe *, but the Inſide of the Globe appears very luminous, and this Fire is perceiv'd to be in greater Quantity in this Experiment, than in that immediately after mention'd *.

2474. But the Action of the Electricity does alſo ceaſe on the Inſide when

when the Air is drawn out *, which ſeems to overthrow what we ſaid of the more eaſy Motion of the Atmoſphere in Vacuo: But yet it is not probable that it ſhou'd move no whither in this Caſe. On the contrary, it ſeems to go the ſame Way as the Fire, and to move that Way where there is the leaſt Reſiſtance; and that the ceaſing of the Action of Electricity is to be attributed to the want of Air, by Means of which, *the Threads are mov'd by the Atmoſphere*; in the ſame Manner, as Fire, which freely penetrates all Bodies, *by Means of* the Vapour *, or *the Air*, (for there is no Exploſion of Gunpowder without Air) acts upon them violently. * 2469. 2475. * 2442. 2446.

But laying aſide Conjectures, though they have a great many Experiments for their Foundation, let us return to other Things relating to Fire. But ſeveral Experiments are to be made in Vacuo, in which Friction is requir'd, which muſt be made with the following Machine.

A MACHINE,

Whereby Bodies are whirl'd round ſwiftly in Vacuo.

G is the Plate of the Air-pump *, upon this is laid the croſs Piece of Copper ADB, which is faſten'd, by a Screw which goes through the Hole *v*, whereby the Pipe is join'd to the Plate, through which the Air is exhauſted †. This croſs Piece is ſo diſpos'd, that the Hole *l* may anſwer to the Hole in the Middle of the Plate G *; for which Reaſon there is below the croſs Piece a † ſhort Cylinder, ſtanding out, which goes into the Hole of the * Plate. 2476. Pl. 80. Pl. 81. Fig. 1. * 2143. † 2152. * 2154.

Into this Hole of the Plate, underneath, is put the Collar of Leathers *p*, whoſe Cover is *d* *. To this is join'd the Copper Plate * *n n*, to which the ſmall Pillars *o*, *o*, made of the ſame Metal, adhere. 2477. * 2155.

Theſe being thus join'd together, we put the Axis *g a b* through the Hole *l*, and through the Collar of Leathers. It's Part *a b* is thicker than the reſt of it, and has a Screw upon it; the Part *f* is ſmaller and cylindrical; the Leathers in the Collar ſurround this, and during the turning about of the Axis, theſe Leathers hinder the Air from getting in. 2478.

To this Axis at *g*, where it is ſquare, is join'd the little Wheel *r*, which is faſten'd by Means of the Screw *h*. This Wheel is dodecagonal, the Sides being a little hollow'd, that the Angles, whoſe Sharpneſs is taken away, may ſtand out the more; the Dodecagon is inclos'd between two thin round Plates, which are prominent 2479.

every Way, that the Rope, of which I ſhall ſpeak afterwards, may be kept in it's Place.

The ſmall Plate *i i*, is applied to the Pillars *o*, *o*, and kept there by the Screws *y*, *y*; this Plate ſuſtains the Axis, whoſe End *z* goes into the Cavity *k*.

Upon the croſs Piece A D B ſtand the two Pillars C, C, which ſuſtain the Plate H, H, which is faſten'd with the Screws *m*, *m*. In the Middle of this Plate there is a Piece with a Hole in it, to receive the End *q* of the Axis ſo often mention'd.

2480. To the Plate A B of the croſs Piece are applied the ſmall Plates T, T, upon which ſtand the elaſtic Plates E F, E F. The Plates T, T, are faſtened by Means of the Screws *e*, *e*, *e*, *e*, going through Slits in the Plates into the Holes *x*, *x*, *x*, *x*; and by this Method the Plates may be faſtened at different Diſtances from the Axis.

2481. The Parts hitherto mentioned are of Copper, and are ſufficient, when Experiments are to be made, in which there is required a ſwift whirling about of the Axis, and a greater Friction. The Axis then goes through the Body, which is to be whirled about, and the Bodies, by which it is to be rubbed, are joined to the Plates E F, E F, as will be explained more diſtinctly in the particular Experiment.

2482. All this Apparatus is covered by the Receiver R *, and the Air
* 2157. is exhauſted. The Rope is put about the little Wheel *r*, and wooden Handles are joined to the Ends of it, which are held in the Hand.

The Rope being now ſtretched, if the Hands be moved alternately; the Axis will turn firſt one Way and then the other.

ADDITIONS

To the foregoing Machine, when a more violent Friction, or a Motion for a longer Time, is required.

In theſe Caſes a Wheel muſt be applied to the Machine.

2483. To the Sides of the Box, which contains the Air-Pump, are applied, and faſtened with Screws, Boards three Inches broad, whoſe Thickneſs appears at K and K. To theſe are joined the ſmaller Boards L, L, to which is applied the Board I I, in the Middle of which there is a ſmall Braſs Pipe, through which the Axis of the Wheel Q paſſes; the other End of this Axis goes into a like Pipe, which is faſtened to the ſolid Wooden Piece, which ſtands upon the Bottom of the Box, and is faſtened with Screws.

2484. The ſmaller ſolid Wooden Pieces N, N, are joined to the Boards K, K; through theſe ſolid Pieces go the Iron Tails of the Wooden

Pulleys *t*, *t*; a Part of which Tails is ſquare, and Part of them makes a Screw. The Rope goes about the Wheels Q and *r*, and paſſes over the Pulleys *t*, *t*, between which the Rope is horizontal; but one of the Pulleys is raiſed a little higher than the other. The Rope is ſtretched, by turning the Screws *c*, *c*.

By turning round the Wheel, the Axis is ſwiftly whirled about, though there is a great Friction between the Body whirled about and the others, which are joined to the Plates EF, EF. The Rope in this laſt Caſe muſt be ſtretched more. 2485.

Experiment 10.

Take a Glaſs Globe of three Inches Diameter, or two Inches and an half, which has a Hole at each Side; the Parts where the Holes are may be cylindrical. The Axis *a b* * is put through theſe Holes, that the Globe may be whirled about; the Parts of the Globe, where the Openings are, are covered with the Cork *s*, *s*, and it is faſtened by Means of the Screws O, O. The loweſt of theſe is faſtened, by a ſmaller Screw *a*, which goes into the Hole *b*; the Globe is faſtened by turning the upper Screw. 2486. Plate 80. * 2478. Pl. 81. F. 1.

The ſolid Pieces of Wood S S, are joined to the Plates EF, EF, and are ſurrounded with Paper; theſe ſolid Pieces are applied cloſely to the Globe, and faſtened by the Screws *e*, *e*, *e*, *e*.

Every thing elſe being diſpoſed, as has been ſaid in the Deſcription of the Machine, the Air muſt be exhauſted from the Receiver *. * 2482.

The Globe, being thus faſtened, together with it's Axis in Vacuo, is ſwiftly whirled about, by the Motion of the Wheel Q, and there is a Friction *. * 2484.

If the Experiment be made in the Dark, the Globe will appear lucid; and the Motion being continued, that the Globe may be heated by the Friction, the Light is indeed increaſed, but then it is obſerved to be fixed in the Places where the Friction is. 2487.

It follows from this Experiment, that *the Fire, contained in Glaſs, does not want Air, to make it appear*; for the Glaſs grows hot, and ſhines, the internal and external Air being taken away. 2488.

The like Experiments may be made with other Bodies.

Experiment 11.

That Quickſilver contains Fire is plain, from Experiments. For if Mercury well cleaned be ſhaked about in a Glaſs, it will appear luminous. 2489.

Expe-

Experiment 12.

2490. The Light is more ſenſible in a Place void of Air.

If you put a ſmall Quantity of Mercury into a Glaſs Globe; the Globe may be whirled round, as has been explained before *, which will be delightful to ſee, if the Glaſs be moved ſlowly.

* 2459.

2491. The Globe, that has the Mercury in it, is exhauſted by joining to it a Pipe about two Foot long, and by joining the other End of the Pipe underneath, to the Hole in the Middle of the Plate of the Air-Pump *.

* 2154.

Then if you cover both that Hole and the Hole through which the Air is drawn out with a Receiver, put upon the Plate mentioned, the Air will be eaſily drawn out of the Globe.

Experiment 13.

2492. A ſmall Quantity of Mercury well cleanſed is poured into the Pl.81.F.2. Glaſs Bottle A; the Air is drawn out, and the Bottle is exactly cloſed with a Glaſs Stopple. If this is ſhaked about in the Dark, the Mercury will appear luminous.

2493. In order to exhauſt the Bottle, it is laid upon the Plate of the Air-Pump; it is covered with a Receiver open at Top, and the Aperture is cloſed with a Cover, to which a Collar of Leathers is join-

* 2155. ed *. To the Braſs Wire, which goes through the Collar of Leathers, is joined a Box, which is filled with ſoft Wax, into which the upper Part of the Stopple is thruſt. The Stopple is ſuſtained by the Coheſion of the Wax, and is ſo ordered as to anſwer to the Mouth of the Bottle.

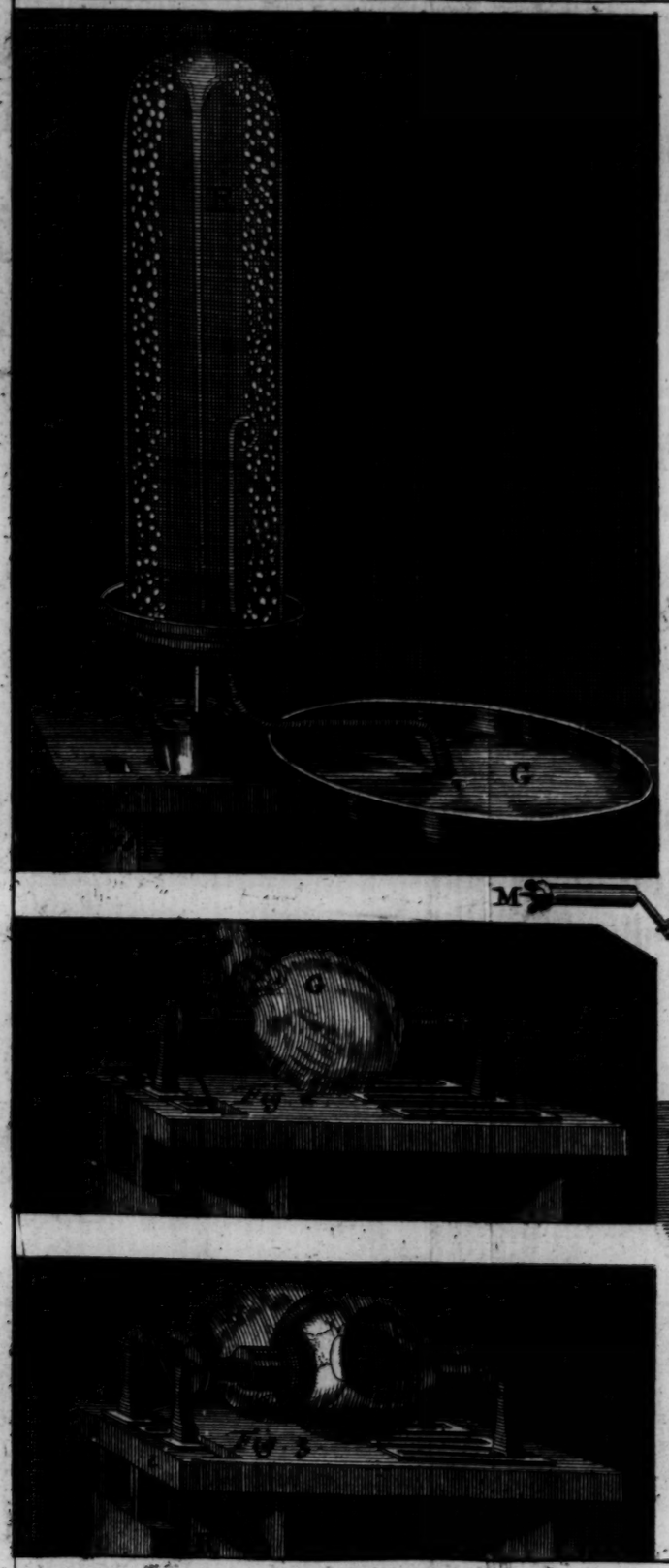
The Air is taken out of the Receiver. The Braſs Wire is thruſt down, and the exhauſted Bottle is cloſed, the Air is admitted into the Receiver, and the Stopple is preſſed tight.

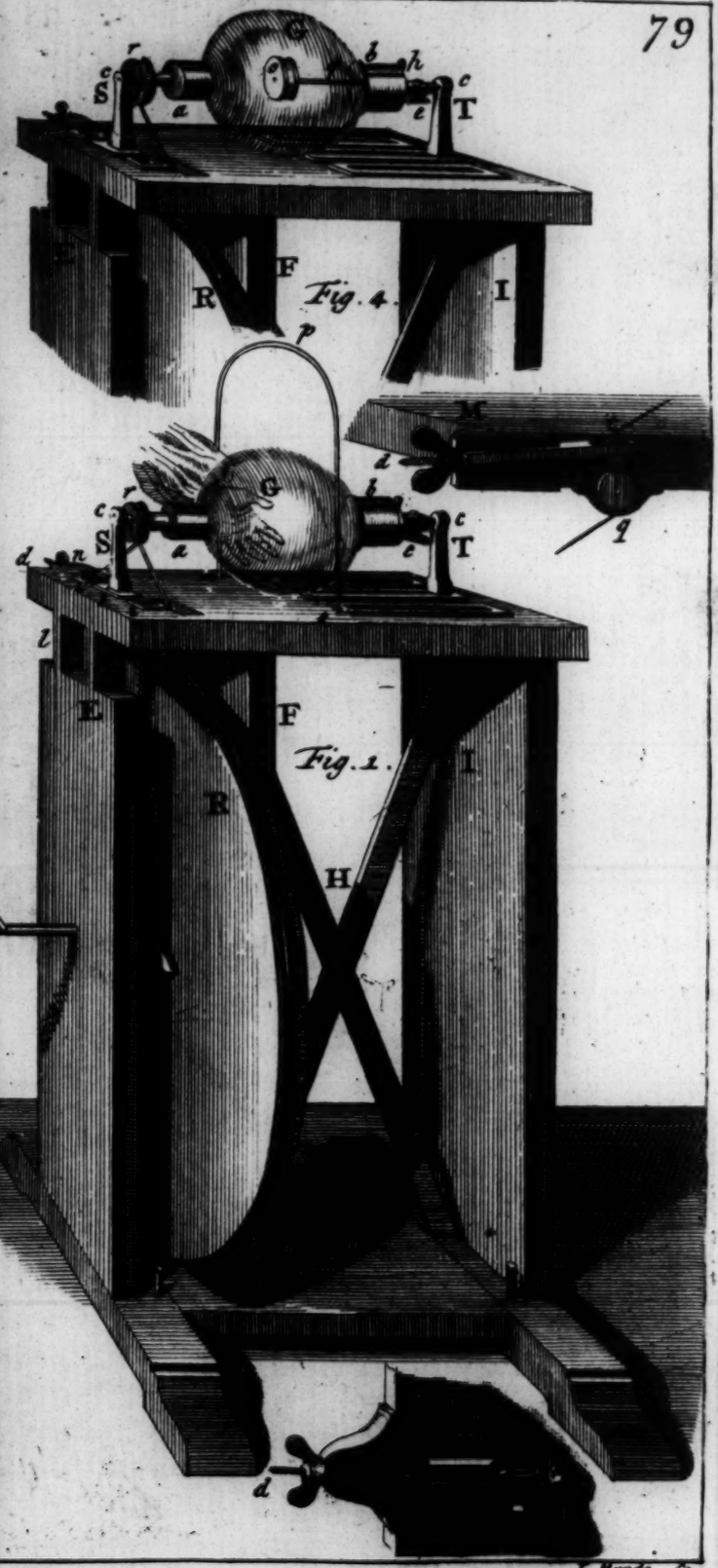
Experiment 14.

2494. Take a Braſs Plate O, and ſcrew on to it the Pipe E E, whoſe Pl.79.F.5. other End is ſcrewed to the Air-Pump *, that the Air may be drawn

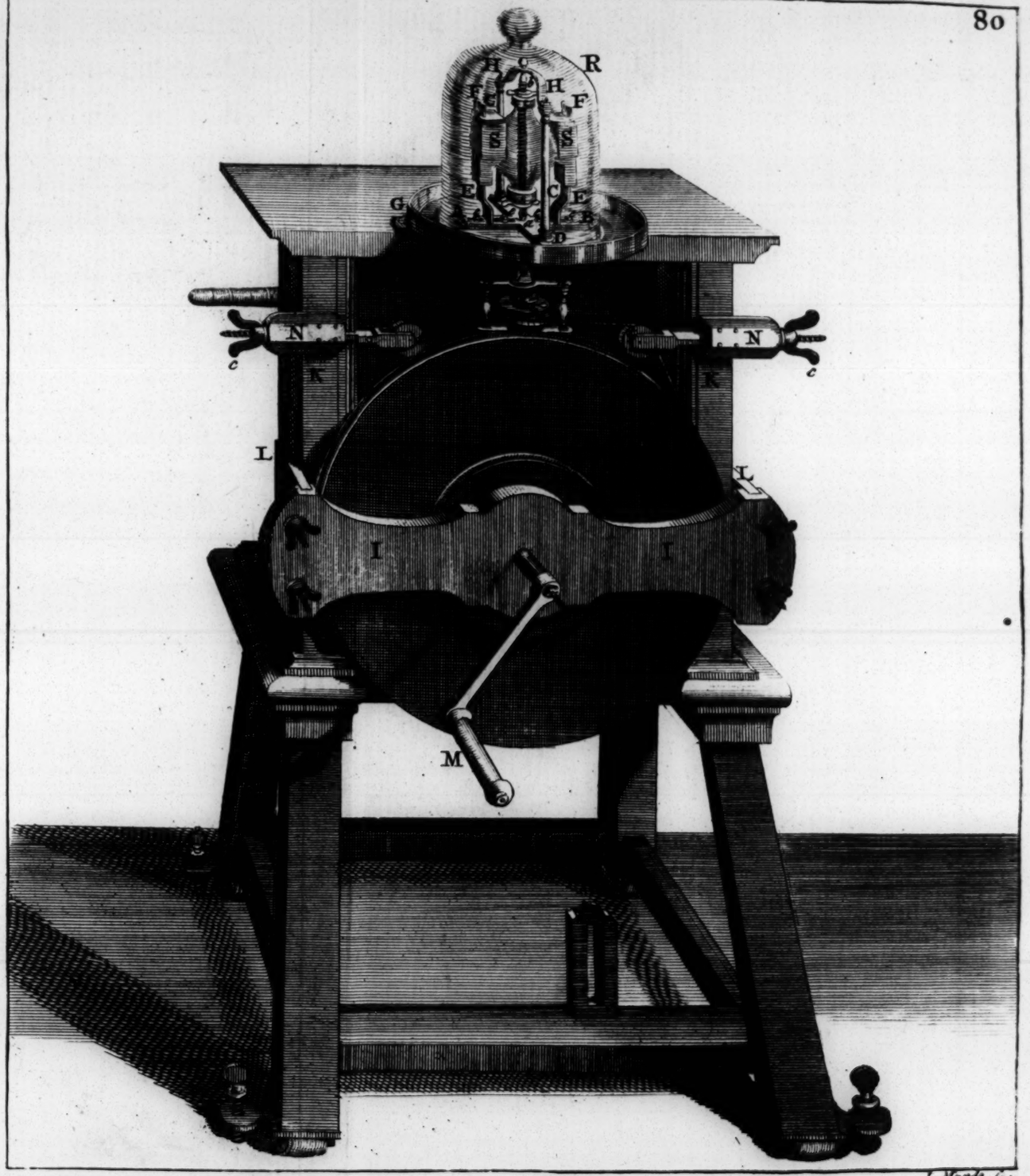
* 2152. out from the Glaſs Receiver R laid upon it. The Pipe, through which the Air is drawn out, muſt ſtand up beyond the Plate in the Receiver about four or five Inches, be bent, and have a ſmall Hole in it; which muſt be taken Care of, for Fear any Mercury ſhould get into the Air-Pump.

The Middle of this Plate, has a Braſs Pipe B, which has a ſmall Glaſs Tube within it; the lower Part of the Braſs Pipe which is ſhut,





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ſhut, comes down almoſt to the Bottom of the Veſſel V, that contains very clean Mercury: There is an Hole in the Side of the Pipe, exactly ſhut by the Pin A; there is a Glaſs Tube at *b*, at the upper End of the Pipe B, ſtanding out, which goes into the Veſſel R, and has a ſmall Aperture.

The Height of the Receiver R is about ſixteen Inches, and it's Diameter four Inches; pump the Air out of it, and then open the Hole in the Side of the Pipe B, and the Mercury will, by the Preſſure of the external Air, violently enter the Pipe, and ſpout up through the Glaſs Tube, and ſtrike againſt the Top of the Receiver R with great Force.

The Experiment muſt be made in a dark Place, and the Mercury will appear luminous.

Mercury, if Metal is not mixed with it, may be well cleanſed by the following Method. We put the Mercury in an open Veſſel together with Water and white Sope upon the Fire; when the Water boils up violently, the Mercury is moved about with ſmall Rods; then, by repeating the Lotions with hot Water, the Mercury is cleanſed from the Greaſineſs of the Sope; then it muſt once or twice paſs through a Paper Funnel, whoſe Spout is ſmall: This dries the Mercury, and clears it of all the Dregs. 2495.

Many hard Bodies emit Light by being rubbed. 2496.

Experiment 15.

Take two Pieces of Chryſtal and rub them together; they immediately become luminous; but the Light is more vivid, where the Contact is. 2497.

Experiment 16.

If the well known chymical Preparation of Urine, which is called *Phoſphorus*, be kept in Water, and then you take out ſome of it, and roll it up, ſo as to make a kind of Pencil, with which you write upon a Piece of Paper, the Letters will appear all Fire, if you put the Paper in a dark Place. When you take the Phoſphorus itſelf out of the Water, it will grow hot and ſmoke; all which ſhews, that the Phoſphorus contains a great Quantity of Fire in it. 2498.

In this Experiment *we may obſerve that Water acts ſenſibly upon the Fire contained in the Phoſphorus*; for *it keeps it in*, ſo long as the Phoſphorus is covered with the Water; but as ſoon as the Water is taken away, the Heat and Smoke immediately ſhew that the Fire iſſues out of the Phoſphorus. 2499.

CHAP. XII.

Of the weaker Motion of Fire, where we ſhall ſpeak of the Communication of Heat.

2500. *WE obſerve a three-fold Motion in Fire.*

2501. The firſt is that by which Heat is communicated, and Bodies dilated, without any Separation of their Parts, or Change of their Order; this muſt be treated of in this Chapter.

2502. The ſecond, which differs only from the firſt in Degree of Intenſity, is that by which the Parts of Bodies are diſſolved, or move amongſt themſelves; we ſhall conſider this in the following Chapter.

2503. The third and laſt is, that it moves in ſtrait Lines, as we diſcover in Light; of which I ſhall ſpeak in the next Book.

2504. *One hot Body communicates Heat to another, which is not ſo hot, upon their mutual Application, but loſes ſome of it's Heat in the Action.*

2505. From whence we gather, that *the Fire moves until* there happens to be an Equilibrium between the Actions of adjacent Bodies: And in that Caſe we ſay *the Degrees of Heat are equal.*

2506. It follows from that Equilibrium, that *however different the adjacent Bodies are, theſe act in the ſame Manner upon Thermometers.*

EXPERIMENT 1.

2507. If a Thermometer be ſuſpended in the Air above the Surface of any Fluid, it will have the ſame Degree of Heat as a Thermometer, which is immerſed in the Fluid, whether it be Water, any Oil, Spirit of Wine, or any other Fluid.

2508. But this Equilibrium in the Actions of the Fire contained in different Bodies will not happen till after ſome Time.

2509. We further deduce from this Equilibrium, that *in all Bodies the Heat is equally diſperſed throughout them.*

2510. As alſo we ſee why Bodies ſeparated and ſurrounded with Air, or any other Fluid, through which the Heat is equally diſperſed, do acquire equal Degrees of Heat,

EXPERIMENT 2.

2511. We make uſe of two Cylinders A and B, the firſt of Marble, the
Pl.81.F.4. ſecond of Wood. They are hollowed cylindrically in the Middle in ſuch Manner, that Thermometers may be put into the Hollows of them;

them; we made uſe of the ſmall ones *c*, *d*, mentioned above *, and one of which is repreſented in Fig. 3. * 2449.

After the Thermometers are put in, the Apertures of the Cavities are cloſed; the Stopple *a*, of the Cylinder A, is of Marble, the other *b* is of Wood; by putting Wax round all Communication with the external Air is cut off.

We make uſe of a third Thermometer alſo EF, which has alſo been mention'd above *; this is put between the Cylinders. * 2449.

The Heat of the Air, ſurrounding the Bodies, being alter'd, the Thermometer EF immediately ſhews the Alteration; if the Temper of the Air remains the ſame, the Thermometer *d* will ſhew the ſame Degree of Heat; if it be continued, *c* will be diſpoſed in the ſame Manner. 2512.

I have always obſerv'd, the Alterations to be thus ſucceſſive, and laſtly equal, for many Months.

It is moreover manifeſt from hence, why the Steam of the Surface of boiling Water, included in a Veſſel, has the ſame Degree of Heat as the Water; and why the Heat is not increaſed when the Vapours are accumulated; and not diminiſh'd, when even a great Quantity of Fire goes out of a given Hole along with the hot Vapours. 2513.

We have ſaid that Bodies of the ſame Heat act in the ſame Manner upon the Thermometer, and this happens, becauſe of the ſmall Quantity of Liquor contain'd in the Thermometer; theſe Actions do not ſenſibly change the Heat of the Bodies. 2514.

But *in many other Caſes Bodies equally hot do not act after the ſame Manner upon the ſame Body*; neither in different Bodies, encompaſſed by the ſame Fluid, equally hot every where, will the Heat become equal to the Heat of the Fluid itſelf in the ſame Time; as we have ſeen in the laſt Experiment. 2515.

Whence it follows that *ſome Bodies are more difficult to be heated than others*, and that from a twofold Cauſe: For the Parts of all Bodies are not mov'd with the ſame Eaſe, and Fire enters ſome with more Difficulty than it does others. 2516.

It is manifeſt, that in Heat there is requir'd a certain Agitation of the Parts of a Body; becauſe upon increaſing the Heat, this Agitation becomes ſenſible: But the Parts of Bodies are different, and theſe in different Bodies do not only differ in Denſity but Coheſion too; and therefore the Agitation cannot be communicated to them with the ſame Eaſe; conſequently unequal Actions of Fire are requir'd to the Communication of equal Degrees of Heat: And *the Heat is not proportional to the Quantity of Fire.* 2517. 2518.

EXPERIMENT 3.

2519. If a Perſon puts both his Hands, when they are equally hot, one upon Wood, and the other upon Marble, both equal in Bulk, and equally hot, but the Heat of which is ſenſibly leſs than that of the Hands; the Hand, which lies upon the Marble, will loſe more Heat, and communicate a leſs Degree of Heat to the Marble, than that Degree which the Wood has acquir'd from the Hand laid upon it, which does not loſe ſo much Heat. Theſe Things are ſo ſenſible, as to require no other Meaſure.

2520. It is alſo manifeſt from Experiments that *Fire does not penetrate all Bodies with the ſame Eaſe*. This is what we have obſerv'd al-
* 2400. ready *, as likewiſe that *the hotter the Body is, the more eaſily will*
2521. *Fire penetrate into it*. A burning Speculum produces a leſs Effect,
2522. that is, reflects a leſs Quantity of Fire when it's Heat is increaſed; which is a Sign that there is a great Quantity of the adventitious Fire that enters into the Speculum and there ſtays.

2523. Alſo the Effect of this Speculum is diminiſh'd, when the Sun's Rays paſs through the Air which has been already heated by them; and this ſhews that Fire enters hot Air in a greater Quantity than it does cold Air.

2524. *Thoſe Bodies which are the moſt difficult to heat, preſerve their Heat the longeſt*, whilſt they communicate Heat to leſs hot, adjacent Bodies.

2525. When a Body gives Heat to ſuch Bodies as are near it, the Parts in it's Surface loſe ſome of their Heat, to which Parts the Fire contain'd within the Bodies does then come; therefore the Diminution of the Heat is ſucceſſive, and the central Parts keep their Heat the longeſt.

2526. Hence we ſee, that *a Body may keep it's Heat a long Time, if it be involv'd within other Bodies*; and the Heat will continue a longer or ſhorter Time, according to the Difference of the Bodies in which it is involved.

2527. This appears by daily Experience, and particularly is obſerv'd *in hot Water*, in which *the Heat is preſerv'd by the circumambient Air*.

EXPERIMENT 4.

2528. Take two equal Veſſels, about three Inches high, and about an Inch and half wide, or leſs. Put an equal Quantity of boiling Water into each of them; let one of them be ſet upon the Air-Pump Plate, and exhauſt the Air out of the ſmall Receiver put over it.

it. Whilſt the Preſſure of the Air is diminiſhing, the Water boils violently, and Fire goes out of it. For the Air being let in, we find the water to be warm; whilſt the other, which remain'd expoſed to the Air in the open Veſſel, loſes only a little of it's Heat.

One may obſerve ſomething like this in Wood that emits Light; for ſome Wood that is rotted in the Ground emits Light, when it is taken out; the Earth that encompaſs'd the Wood kept in the Fire, which goes out when that is remov'd, and the Wood continues to emit Light for ſome Days. In an exhauſted Receiver, the Light is ſoon deſtroy'd, and is not reſtor'd by the Re-admiſſion of the Air. 2529.

Whilſt Fire expands itſelf every Way, and increaſes the Heat of adjacent Bodies, it does not tend to all Parts with the ſame Eaſe *; but if it's Motion towards ſome Parts be more difficult, it will be increaſed towards other Parts; as may be obſerv'd in a Plate, or Iron Cylinder, having one End red hot, and the other no ſenſible Heat; for if the red hot End be immers'd in cold Water, the other End will grow hot. 2530. * 2520.

The Fire which enters into Bodies, puts their Parts into Motion *; the Parts mov'd act upon the Fire contain'd in them, and increaſe the Motion of it; therefore, when extraneous Fire acts upon a Body, *the Heat* thereof *is not only increas'd by the Action of that Fire, but alſo by the Increaſe of the Fire that was within the Body before*; great Fires confirm the Truth of this, and demonſtrate that it is ſo in all burning Bodies; for we can form a Judgment of what happens in ſmall Motions, from what is ſenſible in great ones. 2531. * 2517. 2532.

We ſhall now ſpeak more particularly of that increas'd Motion.

CHAP. XIII.

Of the more violent Motion of Fire. Where we ſhall ſpeak of the Diſſolution of Bodies, cauſed by the Action of Fire.

WHEN the Motion of Fire is increas'd, the Effect of it is the turning of a Solid into a Fluid *, and of this laſt into an elaſtic Fluid, as has been ſeen *. But when the Heat of the Fluid is increas'd, before it is turn'd into an elaſtic Fluid, the Parts of the Body itſelf have a moſt violent Agitation amongſt one another, ſo as *to cauſe the Fluid to boil*: For performing which Effect, 2538. * 2437. * 2440. 2534.

the Action of the Fire need be ſo much the leſs as the Fluid is leſs compreſs'd.

EXPERIMENT I.

2535. Pour warm Water into a Glaſs Veſſel, and put it on the Air-Pump Plate; cover it with a Receiver, exhauſt the Air, and it will boil violently. It is manifeſt enough how the increaſe of the Compreſſion cauſes it to boil with more Difficulty.

2536. And the greateſt Degree of Heat that the Fluid can acquire, depends upon that Compreſſion, as may be gather'd from the Experi-
* 2528. ment above-mention'd *.

2537. The ſmall Parts of all Bodies are not ſuch, that the Bodies become Fluids upon the leſſening of the Coheſion of thoſe Parts, notwithſtanding their being ſeparated from one another by the Action of the Fire.

2538. The Solution of Bodies when they become Fluids is call'd Fuſion: And the Converſion into an elaſtic Fluid is call'd Evaporation,
* 2537. and Exhalation. Alſo the third Separation of Parts above mention'd *, is call'd the Combuſtion or burning of Bodies, and ſometimes their Calcination.

2539. We have already ſpoken of Fuſion, Evaporation, and Exhala-
* 2437.2440. tion *; what has been ſaid, may alſo be referred to Combuſtion and Calcination: But their Difference muſt be attributed to the Frame of the Bodies themſelves.

2540. But what relates to Combuſtion and Calcination, is deduced from
* 2436.2517. what has been ſaid about Heat *; who does not perceive, that upon the Increaſe of the Motion of the Parts, they muſt at length be diſſolv'd.

2541. But before we ſpeak of Combuſtion, *the Parts* themſelves, *ſeparated in Exhalations*, muſt be conſider'd.

Theſe *being intimately join'd with Fire fly off by the Motion of the Fire.* Amongſt theſe the Particles of Water turn'd into Vapour are remarkable; which demonſtrate, that Fire and Water are not
2542. ſuch oppoſites, as is commonly thought; for the *Fire adheres to all* the *watery Particles, and* hinders them from joining with the neighbouring Particles; but the Fire *can no way alter them*; for upon the abſence of that, they meet again, and are reſtor'd to Water.

2543. Vapours aſcend on high through the Air, and are ſuſtain'd at different Heights, according to the different Conſtitution of the
* 1477.2110. Vapours themſelves and the Air *. They are often not perceiv'd; then

then if their Heat be diminiſh'd, they come nearer one another and form Clouds; if there is a greater Diſſipation of Fire the Vapours return again to Water, and fall in Rain.

We alſo obſerve that Vapours in the Air, which were inviſible, appear on a ſudden, if the Denſity of the Air be diminiſh'd 2544.

EXPERIMENT 2.

This Experiment may be made with the Air-pump, when any Experiment has been made with Water in Vacuo. When the Air is let in the Vapours for the moſt Part adhere to the inner Surface of the Receiver; but if the Glaſs be clean, they immediately recede, if the Pump be work'd anew, to extract the Air again; then nothing appears in the Receiver; but if you continue to exhauſt the Air the Vapours become viſible; which are taken out with the Air, if this be all exhauſted. 2545.

There are many Exhalations different from thoſe of Water; all theſe, as they are ſeparated from Bodies by the Action of Fire, contain a great Quantity of Fire; and ſome particularly conſiſt of Particles, which may be burnt, of which I ſhall ſpeak preſently. What elſe belongs to this Matter, and is not foreign from our Deſign, has been explained in the third Chapter of this Book. 2546.

The ſeparated Parts of moſt Bodies, that are burned, are earthy, watery, and oily or ſpirituous. 2547.

We call earthy Parts thoſe that remain after the Body is diſſolv'd by the Fire, that is, the Aſhes, which indeed may be hot, but cannot be burned. 2548.

We call thoſe watery Parts, which are chang'd into Vapours, and expell'd by the Action of the Fire; but which, being collected together, upon the leſſening of the Heat, are turned into Water. 2549.

Laſtly we call thoſe Parts oily and ſpirituous, which are the only Food of the Fire, by whoſe Action they are diſſolv'd, whilſt thoſe Parts increaſe that Action. 2550.

Thoſe Parts are ſo diſſolv'd by the very violent Action of the Fire, that there is no forming a combuſtible Body of them anew: Then theſe are ſaid to be conſum'd: But if the Action of the Fire upon theſe Bodies be leſs violent, they will indeed be turn'd into a thick elaſtic Fluid, which we call Smoke; but this is combuſtible, and when collected together, forms a ſoft Body, which is alſo capable of burning. 2551. 2552.

When the Heat of theſe Parts is increas'd ſo much that they burn, they will emit Light, and form Flame during their Separation 2553.

from

from the Body; ſo that Smoke and Flame have no Difference but in their Degree of Heat; and Smoke upon increaſing it's Heat will be turned into Flame, and by that Means be conſum'd.

Experiment 3.

2554. Pl.81.F.5. Having blown out the Candle C, which ſends out the Smoke F, let another lighted Candle A be brought near it; the Smoke of the firſt will be chang'd into Flame, and by that Means the Candle C will be lighted, which is ſix or eight Inches diſtant from the other.

2555. We muſt obſerve, with regard to *Flame*, that it *has the Figure of a Pyramid* in the Air: The Reaſon is this; the Flame is lighter than the Air, and ſo aſcends; but the Parts which form it, are conſtantly diſpers'd, with a very violent Motion, and therefore it is continually leſſen'd, and but a few Parts come to the upper End of the Flame, which therefore is very ſlender.

2556. Setting aſide this Diſſipation, Flame is cylindrical; for it continually tends towards a ſpherical Figure; but it is carried upwards, and the aſcending Parts are ſupply'd by new adventitious Parts. For this Reaſon Flame may be very much extended; if, whilſt it is ſurrounded, this Diſſipation is prevented, or at leaſt diminiſh'd.

Experiment 4.

2557. Pl.82.F.1. Join together four Candles at C, to make the Flame the thicker; and let it paſs through the Tube A B, which is broadeſt at A, and almoſt a Foot long. The Flame will aſcend above the Tube to D in ſuch Manner, that the Height BD will want but little of the whole Length of the Flame, when the Tube is laid aſide.

2558. If, upon leſſening the lateral Diſſipation, the Flame be left to itſelf, which happens, *when a denſer Flame is encompaſs'd by a more ſubtile Flame, the former will extend itſelf very much, and alſo be dilated laterally.*

Experiment 5.

2559. Pl.82.F.2. Pour Spirit of Wine into the Braſs Cylinder C, which is three Inches wide, and two high, to the Height of about three Quarters of an Inch. Put the Cylinder on the Fire, and ſet the Spirit of Wine on Fire. Put a Piece of a Wax Candle into the ſmall Pipe *a*, an Inch high, which has a bent Tail join'd to it, which Candle muſt not ſtand out above the Pipe. Light the Candle, and put it into the Flame of the Spirit of Wine, which then ſurrounds the denſer

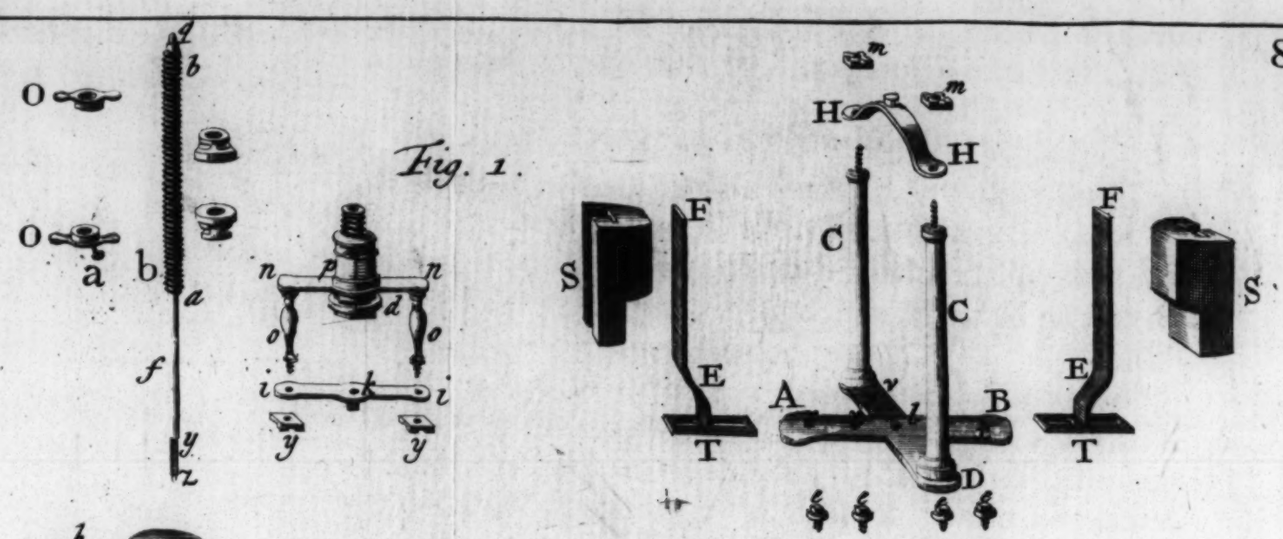


Fig. 1.

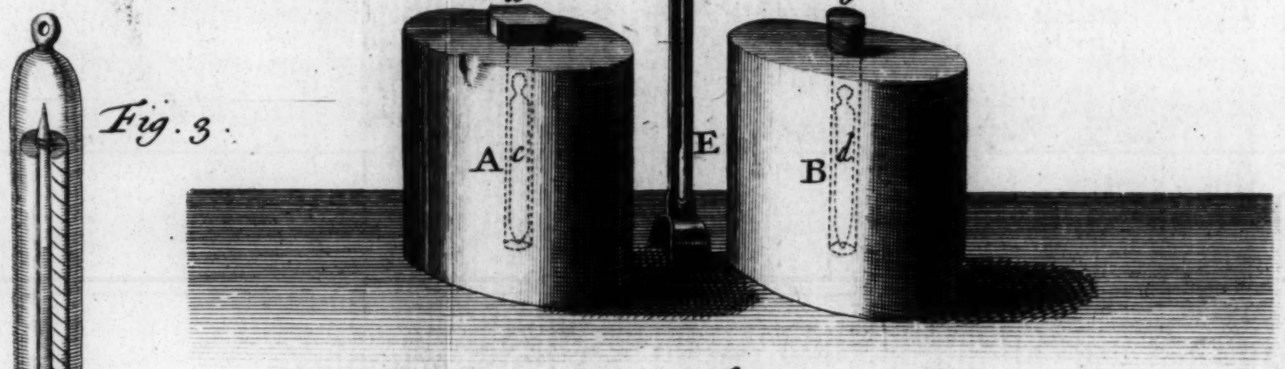


Fig. 4.

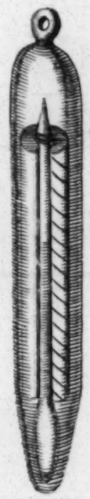


Fig. 3.



Fig. 2.

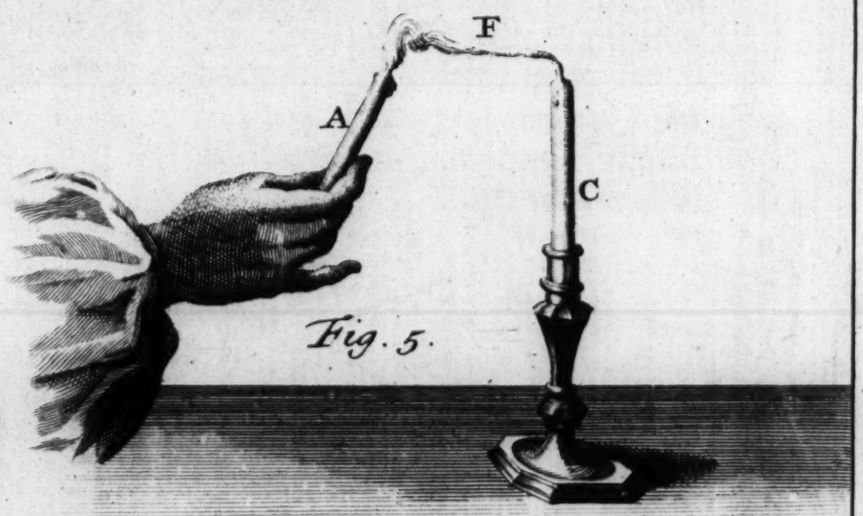


Fig. 5.

J. Mynde fc.

denſer Flame of the Wax; this is dilated, and aſcends higher, than it wou'd if left to itſelf.

The Exhalations, which may be burnt, and are therefore inflammable, moſtly, if not entirely, conſiſt of the Food of Fire; which, by Reaſon of the Fire's acting already upon the Particles *, is very eaſily to be ſet on Fire. 2560. * 2541.

We ſee this in Mines, in which oftentimes, when Flame is brought near them, the Exhalations immediately take Fire with an Exploſion. There is always this Exploſion, when Flame is generated on a ſudden. 2561.

Exhalations often take Fire of themſelves; which is ſometimes to be attributed to the Sun's Rays, collected in paſſing through the Clouds, or by Reflection from them. For the Rays of the Sun, when collected by convex Glaſſes, or Specula, produce incredible Effects, as will appear in the following Book, and the Clouds can do ſomething like this. Exhalations may alſo be ſet on Fire by the Mixture of various Exhalations, in which, by the mutual Action of the Particles, Fire may be very violently excited. Experiments lead us to this Concluſion; for we diſcover in many Caſes, a mutual Action of Particles, in the mixing of Bodies, whereby Fire is excited. 2562.

The Chymiſts furniſh us with many Inſtances; whereby it appears, that two Bodies which are often very cold, by only being mixt together, will take Fire; though they are both Fluids. 2563.

Who will deny that there is ſomething like this in Exhalations, if he conſiders that the Particles of which Exhalations conſiſt exiſt ſeparate from the Bodies, becauſe they are mov'd by the Action of the Fire, which coheres with them *. 2564. * 2541.

We make ſenſible by the *Boylean* Experiment, the mutual Action of mixt Exhalations, although leſs violent.

Experiment 6.

We make uſe of two Phials, one of which contains Spirit of Salt, and the other Spirit of Sal Ammoniac well rectified. When theſe are open'd, Exhalations riſe out of them, but they are inviſible, as long as the Phials are at ſome Diſtance from one another; but if they be diſpos'd in ſuch Manner, that the Exhalations may be mixt together, they immediately become viſible, and aſcend, having the Appearance of Smoke. 2565.

The Exhalations which take Fire in the Air are the Cauſes of ſeveral Phenomena; to theſe we muſt attribute fiery Meteors, as Lightnings and others. 2566.

We muſt now return to what relates to the Action of Fire upon Bodies.

2567. In Bodies, that are calcin'd, there are either none, or but a ſmall Quantity of thoſe Parts, which are the Food of Fire, wherefore before theſe Bodies can be diſſolv'd, it is neceſſary that the extraneous Fire ſhould continually act upon them.

2568. But many things ſeem to ſhew that the Fire cannot immediately exert ſuch an Action upon Bodies, as we obſerve in Combuſtion and Calcination.

2569. In Combuſtion, the Fire unites itſelf with innumerable ſmall Particles, which can no Way be perceiv'd; theſe are mov'd every Way, the greateſt Quantity ariſing from thoſe Places where the Flame is. It can ſcarce be doubted that theſe Particles, as they move

2570. along with the Fire, enter into the Pores of other Bodies; for *it is manifeſt from* many *Experiments*, moſt of which are mention'd by Boyle, *that the Weight of Bodies is ſenſibly increas'd by the Action of Fire*; and particularly if the Flame acts immediately upon them; although the Weight of Bodies, inclos'd in a Glaſs, if the Glaſs is expos'd to the Flame of Spirit of Wine two or three Hours, will alſo be ſometimes increas'd, but in a leſs Degree. This Increaſe of

* 156. Weight, proves the Acceſſion of new Matter *, which has penetrated the Glaſs. But that this Increaſe of Weight cannot be attributed to the Fire, other Experiments prove, from which it ap-

2571. pears, that *the Weight of Fire, if it has any, is not ſenſible to us*; which if it appears from one Experiment only, it is manifeſt that, in all Caſes, in which an Increaſe of Weight is diſcover'd, this is to be attributed to ſome other Matter, carried with the Fire.

Experiment 7.

2572. Lay a Piece of red hot Iron upon the Scale of a very accurate Balance, and make an Equilibrium. If you leave it thus, the Equilibrium is preſerv'd, whilſt the Iron loſes this greater Heat, and is reduc'd to the ſmalleſt Degree of Heat.

2572. Iron is dilated by Heat *; and is ſuſtain'd more by the Air †;

* 2403.2426. therefore it may be imagin'd that there muſt be an Increaſe of the

† 1478.2166. Weight, to make an Equilibrium. But the Difference from this Cauſe cannot be ſenſible in the Experiment, and we ſpeak of a

* 2570. greater Increaſe of Weight *.

The laſt Experiment proceeds in the ſame Manner in Vacuo.

Expe-

EXPERIMENT 8.

We make uſe of two Iron Cubes, having their Sides equal to an Inch, and which are exactly of the ſame Weight; one of them is to be put into the Fire, being firſt laid in a Veſſel, or Crucible, that nothing may adhere to it. 2574.

A ſmall accurate Balance is ſuſpended over the Plate of the Air-Pump, in the Method explain'd above *. The Scales muſt be ſuſpended by Chains, and both the Chains and the Scales muſt be thicker, than what are commonly uſed in ſuch ſmall Balances. * 2167.

When the Iron is red hot, it is laid upon one Scale, and an Equilibrium is made with the other Cube; if any thing is wanting, it muſt be made up with a ſmall Weight. All this muſt be cover'd with a Glaſs Receiver, and the Air exhauſted, and the Equilibrium remains; which is not in the leaſt alter'd, by the Diminution of the Heat of the Iron.

It is confirm'd by Experiments, even ſome that have been made in Vacuo, that the Action of Fire in burning of Bodies, is aſſiſted by the Action of a very ſubtile extraneous Body, which is united with the Fire. For all Combuſtion ceaſes, upon the Removal of the Air, as will be ſeen in the next Chapter. 2575.

Yet Bodies which are to be burnt in the Air, can be conſum'd by Fire, when the Air is remov'd, but only by a continual Action of extraneous Fire, and indeed more ſlowly, the Flame, and violent Agitation of the Parts, ceaſing. 2576.

EXPERIMENT 9.

The ſmall Pieces of Wood *a*, *a*, *a*, *a*, are join'd together by a Wire, which is faſten'd to the End S, of the Braſs Wire S T, which paſſes through the Collar of Leathers P *, which is ſcrew'd on to the Cover O, which is laid on the Receiver R. 2577. Pl.82.F.3. * 2155.

The red hot Iron F, is laid upon the Plate G of the Air-Pump, the Stone L being put between; it is cover'd with the Receiver R, and the Air is exhauſted. If you puſh down the Braſs Wire, the ſmall Pieces of Wood are laid on the Iron ſucceſſively, and there conſum'd; but they emit no Flame.

When a Flint is ſtruck with a Steel, Particles are ſeparated from the Steel and the Stone; they are fiery, and make Sparks, in their Separation: The melted Particles of Metal acquire a ſpherical Figure; thoſe which are ſeparated from the Stone, are conſum'd, are friable, and are reduc'd to a Calx. If the Percuſſion be made 2578.

in Vacuo, we diſcover the ſame Changes; but the Parts, whilſt they are ſeparated, do not become lucid, and there are no Sparks to be perceiv'd.

Experiment 10.

2579. We make uſe of the Machine, deſcrib'd above, for Friction in
* 2476. Vacuo *; with it's Adjuncts, that the Circumrotation may be with
* 2483. the greater Wheel *.

But before we join the Machine to the Plate of the Air-Pump, we lay a Leather on the Plate, upon which Leather the Glaſs Re-
* 2157. ceiver muſt be put *; we alſo apply to the Plate a Piece of Paper, which muſt be contain'd in the Receiver in ſuch manner, that it may not hinder the Receiver from being applied to the Leather, Part of which only is cover'd with the Paper; this has two Holes in it, which anſwer to the Holes in the Air-Pump.

Pl.82.F.4. To the movable Axis *a b* we join the ſteel Cylinder A, of a ſmall Height, through the Center of which the Axis paſſes, and whoſe Diameter is about two Inches and an half, and Height half an Inch.

The Convex Surface of this Cylinder has Grooves, in ſuch manner that the Eminences between the Grooves make Edges, which encompaſs the Cylinder; theſe Edges have eight or ten Inciſions, at Right Angles to them.

The Cylinder is faſten'd between two ſmall round Pieces of hard Wood, by the two Screws *c*, *c*, which are ſcrew'd on with Keys, that the Cylinder may be well fix'd.

Two Pieces of Flint muſt be put into the Pieces of Wood S, S, which are applied to the Plates E F, E F. The Flints muſt be mov'd to the Circumference of the Cylinder, and preſs'd cloſe to it, in ſuch manner that the Plates E F, E F, may be bent downwards a little, and in this Poſition they are faſten'd by the Screws
* 2480. *e*, *e*, *e*, *e*, *.

All this muſt be cover'd with the Glaſs Receiver, and the Wheel muſt be turn'd round; the Particles which are rubb'd off fall upon the Paper, and muſt be gather'd together; and theſe being all remov'd, the Receiver muſt be laid on again, and the Air exhauſted.

Turn the Wheel again, and having let in the Air, remove the Receiver, and gather together again the Particles, which have been ſeparated from the Steel and Flints.

2580. If theſe collected laſt, be compar'd with the firſt, which were collected before the Air was exhauſted, theſe will be found to be like

like the others, if we examine them with a Microſcope. If the Experiment be made in the Dark, we obſerve, during the turning about of the Wheel, that the Receiver is in a manner fill'd with Sparks, when there is Air in it; but when there is no Air we perceive no ſuch Thing, and the Light appears fix'd where the Friction is; the Stones being made lucid by the Friction, as we have ſeen in other Bodies *. * 2486.

CHAP. XIV.

Of the Extinction of Fire, and of Cold.

THE Extinction of Fire is a Ceſſation of it's Motion in that Body wherein the Food of the Fire is waſted *. 2581. * 2550.

It is very evident that Fire muſt neceſſarily be extinguiſh'd, when all its Food is deſtroy'd by the Action of the Fire. But it is very difficult to account for the Extinction of Fire, when it has ſome Food yet remaining.

This we often obſerve when burning Coals are expos'd to the Sun's Rays; for they are put out before they are quite conſum'd, as may eaſily be try'd. But it is very hard to ſhew how it comes to paſs. 2582.

Fire alſo *goes out where there is no Air.* 2583.

EXPERIMENT 1.

Take a red hot Coal of hard Turf, which wou'd not go out of itſelf, without being quite conſum'd, and put it into an open Veſſel, laying it on the Plate of the Air-Pump; cover it with a Receiver, exhauſt the Air, and the Coal will be extinguiſh'd in a ſhort Time. If, immediately after the taking out of the Air, the Air be let in again, in that ſhort Interval of Time, the Coal is not entirely conſum'd, but is reduc'd to that State, that, That which burnt violently, may now be very ſafely handled. 2584.

The Cauſe of this Phenomenon cannot be ſo eaſily diſcover'd; for Experiments demonſtrate that *this Effect cannot be attributed to the Diminution of the Preſſure alone.* 2585.

EXPERIMENT 2.

A Glaſs Receiver, open at Top, is laid upon the Air-Pump; this is clos'd with a Cover, to which is join'd a long, curve, Braſs Tube, which has an Iron End, a Cock being put between. 2586.

The

The Air is exhauſted from the Receiver, and let in through the Tube, which is join'd to the Cover, and ſo diſpos'd, that the Air cannot enter into it, without paſſing through the Flame of red hot Coals. The Air is let in ſlowly, and when the Receiver is fill'd with it the Cover is taken away; and the Air in it ſuſtains the Weight of the whole Atmoſphere. Now if we put into the Receiver through the upper Hole burning Sulphur, or Paper ſet on Fire, it is immediately extinguiſh'd upon it's Entrance into the Receiver.

2587. If this be repeated ſeveral times, the Flame may be thruſt in more and more continually, before it will be put out; becauſe it drives out the Air from the Places that it comes to, and new Air immediately ſucceeds.

2588. Whence it follows, that *ſome peculiar Particles are requir'd, that Fire may not be extinguiſh'd*, which fly off by the Action of the Fire, or become uſeleſs, which happen'd in the laſt Experiment, before the Entrance of the Air into the Tube.

This is illuſtrated by another Experiment alſo.

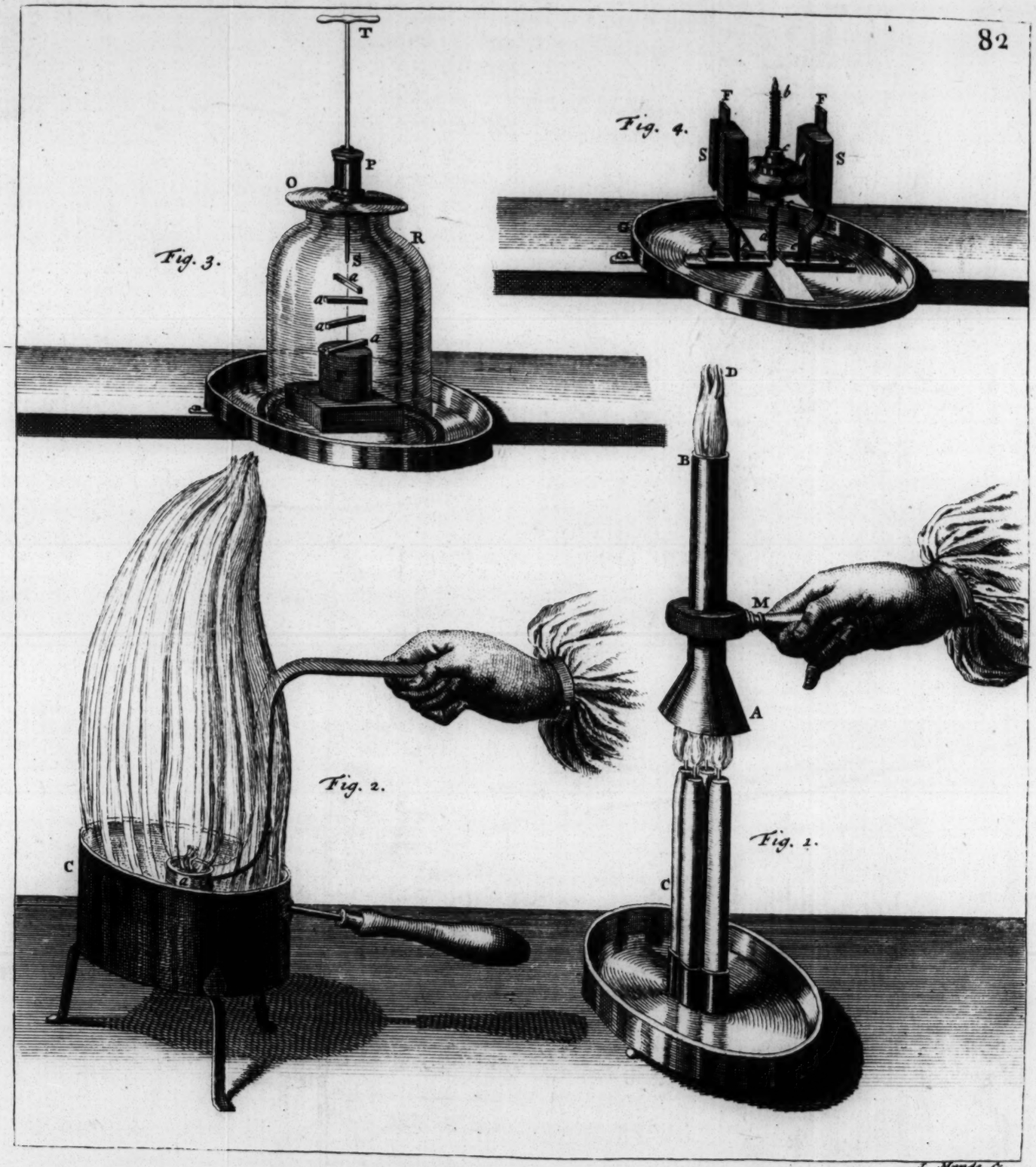
Experiment 3.

2589. A lighted Candle is cover'd with a Receiver, open at top; and that the Air may not come in at Bottom, we lay the Candle, together with the Receiver, upon the Plate of the Air-Pump; and we make uſe of a Receiver, which may be applied very cloſe to it, as in the Experiments concerning Air. The Flame remains in the ſame State, new Air coming in continually at top; but if a Cylinder be join'd to the upper Aperture, that the Air cannot ſo conveniently get in, the Candle will be put out in a ſhort Time; unleſs the Receiver be rais'd up a little at one Part, that the Air may come in at the Bottom; or be admitted, any other Way.

2590. The ſeveral Ways by which Fire is extinguiſh'd, muſt be refer'd
2591. to the want of Air: Thus *Fire which is every Way inclos'd, is extinguiſh'd in a ſhort Time*; to the Performance of which it ſeems, that the accumulated Smoke does not a little conduce.

2592. That Extinction is oftentimes ſuch, that the Fire extinguiſh'd will not be re-kindled, but by bringing new Fire to it, though ſometimes, upon the Admiſſion of the Air, it will re-kindle of it's own Accord, and that too when all Communication with the external Air has been a conſiderable Time taken away. Yet in ſome of theſe Caſes the Fire is not quite extinguiſh'd, although there is not a ſenſible Appearance of the Conſumption of the Fire's Food.

We



T. Mynde sc.

We alſo *refer the Action of Water, when it extinguiſhes Fire, to the want of Air.* 2593.

In the Combuſtion of thoſe Bodies which attract Water, if this, which will not burn, becauſe it contains no Food for Fire, be pour'd upon them, it will immediately touch or cover the Bodies in ſuch a Manner as to hinder the Acceſs of the Air upon which the Fire is extinguiſh'd, unleſs the Quantity of the Water be very ſmall with regard to the Bigneſs and Violence of the Fire: For in that Caſe the Water is immediately chang'd into Vapour, and driven back. 2594.

But when the Bodies are ſuch, that the Water will not immediately touch or mix with, as Oil and greaſy Bodies, the Water will not extinguiſh theſe, unleſs it be pour'd upon them in ſuch Abundance, as to take away the Acceſs of the Air from every Part. 2595.

There are alſo ſome Fluids which, though they will mix with Water, yet, when on Fire, will not be extinguiſh'd by Water; which ſeems to contradict what has been already ſaid *: But the Water cannot apply itſelf to the Surface of theſe Fluids, and be diſpers'd over them, as it ſhou'd be, to hinder the Acceſs of the Air. 2596. * 2593.

The Action of the Water upon the Fire contain'd in the Phoſphorus, which has been already mention'd *, differs from the Action ſpoken of here. For when the Phoſphorus is well lighted, it cannot be extinguiſh'd by Water, and it's Light is more lively where there is no Air. 2597. * 2499.

Experiment 4.

Write upon Paper with the Phoſphorus, above-mention'd, and incloſe it in a Receiver, out of which exhauſt the Air, and the Letters will appear in the Dark more lively, than in the Air, but they diſappear in a ſhort Time. 2598.

When Fire is extinguiſh'd, the Heat is leſſen'd, and therefore that Extinction has ſome Relation to Cold. 2599.

For *the leſſening of Heat is very often*, but not always, *call'd Cold, which is no other than that Diminution.* 2600.

Thoſe Parts that are not ſo hot as the Parts of our Body which touch them, that is, which leſſen the Heat in our Bodies *, are ſaid to be cold; juſt as thoſe Bodies are ſaid to be hot which increaſe that Heat *. 2601. * 2504. * 2409.

Cold with regard to us is no other than the Senſation ariſing in us upon the leſſening of the Heat in our Bodies, and in a cold 2602.

Body

* 2452. Body there is Heat * : But it is leſs than the Heat of our Body,
* 2504. and therefore that diminiſhes this *.

2603. From theſe common Conſiderations alone, that Queſtion is eaſily determin'd, *viz.* whether Cold ought to be aſcrib'd to a Privation of Heat, or to the Preſence of ſome particular Matter, juſt as Heat is owing to the Preſence of Fire. It is very evident that the bare Abſence of Fire is ſufficient.

2604. But we may alſo put another Queſtion, *viz.* whether it is poſſible to have a Diminution of Heat without a certain Sort of Matter, whoſe Particles we may call the Darts of Cold. To this I anſwer, that we have no Experiments to prove there is ſuch a Kind of Matter, and therefore it is impoſſible to give an Anſwer to this Queſtion, for we ought not to deny a Thing becauſe we cannot prove the contrary. But this we know is always very certain, that from whatever cauſe it proceeds, the Diminution of Heat is ſufficient of itſelf to cauſe Cold.

2605. I cannot deny but that there may be ſome ſubtile Particles, which, upon entering into Bodies, do either wholly or partly drive the Fire out of them. But that there are always ſuch, where we find a Diminution of Heat, is what I ſaid does not yet appear. For although there are Particles which do not attract Fire as the Particles of which Bodies conſiſt, but repel it, it does not follow from thence that Heat cannot be leſſen'd from ſome other Cauſe.

But in ſome Caſes the following Experiment ſeems to ſhew that there are ſuch Particles.

Experiment 5.

2606. Take a Mixture of Snow and Sea Salt, and put it into a Veſſel, which ſurrounds a Glaſs fill'd with Water, if this Mixture be ſet on the Fire, the very Moment that it melts, *viz.* that it becomes hot, it does not, like other Bodies, communicate Heat to the Wa-
* 2504. ter * ; but the Water is immediately turn'd into Ice.

2607. If the Water be contain'd in a Tube, which is exhauſted, the
* 2128. Congelations is made with an Ebullition *.

The End of the Fourth Book.

Mathematical

Mathematical Elements
OF
NATURAL PHILOSOPHY
CONFIRM'D BY
EXPERIMENTS.

BOOK V.

PART I. Of the Motion of Light, and it's Inflection.

CHAP. I.

Of the Velocity of Light.

WE have obſerv'd that the intimate Nature of Fire is unknown to us *; this muſt alſo be referr'd to Light. We do indeed deduce many Phenomena of Light from a few Properties of Light, which we diſcover by Experiments; but it will appear from the Phenomena themſelves that many Properties of Light are conceal'd from us. 2608. * 1392.

We have before obſerv'd that Light moves in right Lines *. Light does not go from one Point to another, if there is any Obſtacle in the right Line, which we ſuppoſe drawn between theſe Points. 2609. * 2414.

2610. *If Light paſſes through an Hole, it keeps it's Direction, and is*
* 1744. *not diſpers'd ſideways*, as has been ſaid of Waves *.

Definition 1.

2611. *Any Light whatſoever conſider'd with regard to the Direction of it's Motion, if it be all carried in the ſame Direction, is call'd a Ray of Light.*

2612. We have ſeen that a Body, which emits Light, is ſaid to be
* 2411. lucid *.

2613. *The Surface of a lucid Body, conſiſts of lucid Points, which emit Rays of Light every Way.*

Definition 2.

2614. *A Body is ſaid to be tranſparent, through which Light can paſs, the Right-lin'd Motion of the Rays, in the Body, not being diſturb'd.*

Definition 3.

2615. *Bodies, that intercept Light, are call'd opaque Bodies.*

But there are two Queſtions propos'd with regard to the Motion of Light.

2616. 1ſt. Whether the Motion of Light is to be attributed to a ſimple Preſſure, or whether there is a Removal from one Place to another.

2617. 2dly. Whether the Propagation of Light be inſtantaneous, or ſucceſſive.

2618. I ſhall ſay ſomething of the firſt Queſtion. According to thoſe, who attribute the Motion of Light to Preſſure, the ſmall Globules, which touch one another, are diſpers'd through the whole Space, through which the Light is propagated. The Light appears, when by the Action of the lucid Body, the Globules next the Body are preſs'd, which preſs thoſe next to them, and thus the Propagation is caus'd.

2619. I ſhall only make one Objection to this Opinion. A Globule is furrounded by many others, and, if thoſe are compreſs'd according to different Directions, they likewiſe preſs that very Globule according to different Directions; and this, that all the Rays may keep their Direction, ought to preſs the other Globules according to all theſe Directions; but this cannot be; for all the Preſſures
* 318. are reduc'd to one only *, and a Globe compreſs'd preſſes upon all the adjacent ones, which can reſiſt this Preſſure, whether they anſwer to thoſe that preſs, or not; whence wou'd follow a Confu-

ſion of Rays: Contrary Preſſures wou'd alſo mutually deſtroy one another. But it appears from Experience that innumerable Rays paſs through the ſmalleſt Hole, without any Confuſion. It will be manifeſt from what we ſhall afterwards ſay of Viſion, that this happens, when we ſee many Objects through a ſmall Hole.

If the Propagation of Light be not by Preſſure, it is not inſtantaneous; but it is by Tranſlation from one Place to another, in which ſome Time is conſum'd. Although this general Obſervation be ſufficient to anſwer the firſt Queſtion *; we will illuſtrate it more, and examine, whether we cannot determine the Velocity of Light from Phenomena. 2620. * 2617.

Caſſini and *Reaumur* were the firſt, who attempted to determine the Velocity of Light from aſtronomical Obſervations; the former ſoon chang'd his Opinion, being perſuaded that the Concluſions, which he had drawn from Phenomena, did not follow from them; becauſe all Phenomena did not agree. *Reaumur* continued in his Opinion, and endeavoured to defend it with all his Might; and therefore it is now attributed to him alone: I ſhall briefly conſider it. 2621.

But as we have to do with aſtronomical Obſervations, what relates to the preſent Queſtion, might be more eaſily and fully explained in the next Book; nevertheleſs I ſhall undertake to explain it now, and ſhall mention ſome Things belonging to Aſtronomy; but only ſuch, as immediately relate to our Purpoſe; and I ſhall endeavour to propoſe them in ſuch Manner, that they may be underſtood by thoſe alſo, who have not yet acquired Ideas of the Motions of the heavenly Bodies. 2622.

The Sun, the Fountain of Light, enlightens the Bodies with it's Rays, which move round it; theſe Rays by being reflected become viſible, as will be more fully explain'd, when I treat of Viſion. Amongſt theſe the Earth itſelf performs it's annual Revolution round the Sun. 2623.

The Bodies that move round the Sun, are ſpherical, and opake, and are call'd Planets; we ſhall take into Conſideration one of theſe, call'd *Jupiter*. Round this there move four ſmaller Bodies, call'd Satellites; which revolve circularly round the Center of *Jupiter*. 2624.

Theſe Satellites in their Revolutions paſs through the Shadow of *Jupiter*, and are eclips'd, and indeed every Revolution, if we except the fourth, which is at the greateſt Diſtance, which ſometimes paſſes by the Side of the Shadow.

Aſtronomers have chiefly taken Notice of the inmoſt, or leaſt diſtant of them, and have obſerv'd it's Motion more accurately, than that of the others, in order to determine it's Immerſion into the Shadow, and it's Emerſions out of it.

2625. Pl.85.F.1. Let S be the Sun, A B C D the Orbit of the Earth; I *Jupiter* in his Orbit; E F G the Orbit of the inmoſt Satellite; this paſſes through the Shadow at E F. If the Body of *Jupiter*, and the Orbit of the Satellite, ſhou'd have a Magnitude proportioned to this Figure, they cou'd not be perceiv'd.

2626. The Computations would be very ſimple, if, whilſt the Satellite is carried equably in a Circle round *Jupiter*, in the periodical Time diſcover'd, this turn'd about the Sun in the ſame Manner; but this is not the Caſe; whilſt the Shadow turns about with *Jupiter*, it will not move equably, and in reſpect of that the Computation muſt be corrected; this Correction is call'd *the firſt Equation of the Satellite*. Moreover we ought to have regard to the Time the Satellite remains in the Shadow, which is greateſt, when the Satellite paſſes through the Center of it, and different according to the different Diſtance from the Center, at which it paſſes along. From theſe Obſervations made accurately, the Moment of the Beginning or End of the Eclipſe may be determin'd.

2627. But this Computation is not ſufficient, in the Obſervation of an Eclipſe; the Obſervation differs more or leſs from the Computation, according to the different Situation of the Earth with reſpect to *Jupiter*; and the greateſt Difference wants little of a Quarter of an Hour.

But it is manifeſt, that the Situation of the Earth does not alter the Eclipſe; and that therefore this Retardation muſt be attributed to an extraneous Cauſe.

2628. When the Earth paſſes between *Jupiter* and the Sun at A, the Computation mention'd agrees with the Obſervations; but when the Earth recedes more from *Jupiter*, a ſecond Correction, which is call'd *the ſecond Equation*, is to be made uſe of. This Equation follows the Ratio of the Increaſe of the Diſtance of the Earth from *Jupiter*, whilſt the Earth moves through A B C; and the Eclipſe is retarded in the Ratio of this Increaſe of the Diſtance, meaſur'd in a right Line drawn to *Jupiter*; and in the ſame Manner is diminiſh'd the Retardation in the Motion of the Earth through B D A, in which it draws nearer to *Jupiter*.

2629. This Proportion was the Reaſon, that *Reaumur* attributes the Delay taken Notice of to the Motion of Light, and the Concluſion is

evident; for if at the very Moment, when the Satellite goes out of the Shadow, it is viſible at any Diſtance whatever, it matters not whether a Spectator be at A, or B, or at a greater Diſtance from *Jupiter*, he will perceive the going out from the Shadow at the ſame Time, and the ſecond Equation which has been mention'd cannot take Place; but as it really does obtain, it is no Wonder that this Invention has been, as it were, univerſally approv'd of.

2630. The firſt, who denied that this ſecond Equation of the Satellites was to be attributed to the ſucceſſive Motion of Light, was *Caſſini* himſelf, who had found out with *Reaumur* that an Equation was to be made uſe of in the Computation. His Reaſon for it was this; he perceiv'd that a like and equal Equation, ought alſo to take Place with regard to the other Satellites, if it really depended upon the Motion of Light; he diſcovered indeed a like Equation, but what was much greater, with regard to the other Satellites, and diffrent in every one.

2631. The Opinion of *Reaumur*, which was oppos'd by a celebrated Aſtronomer, ſhortly had a celebrated Defender. Dr. *Halley*, who contracted *Caſſini*'s Tables, relating to the Motion of the inmoſt Satellite, and rendered the Computation more eaſy, made ſome Obſervations, from which it follows that the ſecond Equation is the ſame with regard to the third and fourth Satellite, as the firſt; and thus, having remov'd the Difficulty propos'd by *Caſſini*; he remov'd the Objection made to the Argument of *Reaumur* for the ſucceſſive Propagation of Light.

2632. It is no Wonder, if the Concluſions from different Obſervations do not agree: The ſecond Equation is diſcover'd by comparing the Computation with the Obſervations; but the Computation is founded upon the Tables, made for that Purpoſe, and who will affirm that theſe are accurate enough to ſolve the Queſtion? And it will appear preſently that this Objection was not without Reaſon.

2633. What has been hitherto ſaid, regards the laſt Age, but the Diſpute was not ended with the Age; *Maraldi*, Aſtronomer of the Academy of Sciences, in the Year 1707, oppos'd the Opinion of *Reaumur* with new Arguments, and endeavour'd to add new Force to *Caſſini*'s Arguments, by taking Notice of other Obſervations, from whence it follows that the ſecond Equation ſhould be greater in the remote Satellites than in the firſt.

But the chief thing relates to a more accurate Obſervation of the firſt Satellite; with regard to which he obſerves, that a certain third Equation is neglected, which might ariſe to three Minutes and an half,

half, and which would be to be conſider'd, if, what was ſaid of the Velocity of Light, was true.

2634. *Jupiter* deſcribes an Ellipſe about the Sun, in one of whoſe Foci is the Sun's Center; which the Point is in the Ellipſe we have
* 625. ſeen above *. The greateſt Diſtance of *Jupiter* from the Sun exceeds the leaſt by a Quantity equal to the half of the Diſtance S A of the Sun from the Earth; and the Diſtance of *Jupiter* from the Earth may be increas'd by ſuch a Quantity, by Reaſon of the ſaid elliptical Figure; for S I increaſing, the Diſtance of *Jupiter* from the Earth is increas'd, in whatſoever Part of it's Orbit it be; and the Retardation of the Eclipſe would increaſe according to the Ratio of
* 2629. this Increaſe, if the Reaſoning of *Reaumur* ſhould obtain *.

2635. But *Maraldi* takes Notice of ſome Obſervations, which differ very little from the Computations, and which would ſenſibly err from them, if this laſt mention'd Increaſe of the Diſtance of *Jupiter* ſhou'd be taken Notice of. From whence he concludes, that the Equation laſt mention'd, is not to be receiv'd in the Tables, and that *Reaumur*'s Opinion is to be rejected.

2636. But *England* has produc'd a ſecond Defender of this Opinion. It appearing from many Obſervations, that, the firſt Satellite mov'd a little faſter than according to *Caſſini*'s Tables, *J. Pound* thought upon correcting thoſe Tables, who had made many accurate Obſervations upon *Jupiter*, and the other heavenly Bodies. But the Error of the Tables is ſo ſmall, that it cou'd not be diſcover'd but after many Years.

2637. But this Aſtronomer affirms, that it appear'd to him from many Year's Obſervations, that the ſecond Inequality is the ſame in all the Satellites. And having corrected *Caſſini*'s Tables of the firſt Satellite, which he delivers as more accurately agreeing with the Heavens, he added the third Equation, which *Caſſini* omitted, *Halley* had taken Notice of, and *Maraldi* had ſaid ought to be re-
* 2635. jected *. It is not to be wonder'd at, that Aſtronomers ſhou'd not agree together; we are conſidering an intricate Matter, and
* 2632. which is not immediately deduc'd from Obſervations *: Therefore that might be attributed to one Cauſe, which ſhou'd have been attributed to another, and the Error might not be diſcover'd but by comparing the Obſervations made at different Times; ſo that the Difficulties cou'd be remov'd only after a long Time; in the mean Time there was always ſomething obſcure, which was at length remov'd by the great Aſtronomer laſt mention'd. This Obſcurity was the Reaſon that *Reaumur* himſelf, had deduc'd from his firſt Obſervations,

Obſervations, that the ſecond Equation might increaſe to twenty two Minutes, when the greateſt in *Caſſini*'s Tables is fourteen Minutes.

Now if this ſecond Equation be aſcrib'd to the Motion of Light, to this we ought to attribute the Velocity, with which it comes to us from the Sun in ſeven Minutes Time. 2638.

But the Velocity of Light is not deduc'd from Obſervations made on the Satellites of *Jupiter* only. A few Years ago Mr. *Bradley*, Profeſſor of Aſtronomy at *Oxford*, demonſtrated the Motion of Light from Obſervations made upon the fixt Stars, at firſt jointly with *Molineux*, and which after his Death *Bradley* proſecuted alone, to whom alſo we owe the Concluſions concerning the Motion of Light, whoſe Velocity he determin'd, which did not differ much from that, which we have mention'd *. 2639. * 2638.

In order to underſtand the Force of the Argument, upon which this Concluſion depends, ſome Things muſt be premis'd.

The fix'd Stars are lucid Bodies, and are at Reſt with regard to the planetary Syſtem, from which they are very remote. In this planetary Syſtem, the Earth takes it's Place among the Planets, and moves round the Sun, which is at Reſt, as has been ſaid *. 2640. * 2623.

Let us ſuppoſe the Sun to be repreſented at S; the Circle A B C D to repreſent the Way of the Earth round it; and this to be in the Plane, through which the Center of the Sun paſſes, and is call'd the Plane of the Ecliptick. Let us ſuppoſe in this Center a Perpendicular to this Plane to be rais'd, which we ſuppoſe to be repreſented by S P, and to paſs through any fixed Star. It is no Matter whether or no there really be a Star in the Heavens in this Perpendicular; we ſhall reaſon, as if it were ſo, and this will anſwer our Purpoſe. Pl. 85. F. 2.

If a Spectator ſhould be at S, he would ſee the Star in this very Perpendicular; but if the Spectator ſhou'd run through the Circle A B C D, and the Diameter of it ſhou'd have a ſenſible, though ſmall Ratio to the Diſtance of the Star, this will ſeem to alter it's Situation in the Heavens. The Spectator at A wou'd ſee the Star along the Line A P *a*; being plac'd at C he would ſee it along the Line C P *c*; and in the ſame Manner every where; wherefore the Star would ſeem to run through the ſmall Circle, repreſented at *a b c d*. 2641.

If the Diſtance of the Star ſhou'd be ſo great, that in reſpect of it the Diameter A C, of the Earth's Orbit, might be looked upon as a Point, in which Caſe the ſmall Circle mention'd wou'd be entirely inſenſible, all the Lines, drawn from Points of the Orbit to the 2642.

the Star, might be looked upon as perpendicular to the Plane of the Ecliptic, and would anſwer, as to Senſe, to the ſame Point in the Heavens, with the Perpendicular at S; in which the Star wou'd always appear, if Light came to us in an Inſtant, as was
* 2640. ſuppos'd in the foregoing Reaſoning *.

2643. But if in this Caſe, in which the Star is ſo remote, we ſuppoſe, the Light to be propagated from the Star with a certain Velocity, whilſt the Earth runs through it's Orbit, a Spectator will ſee it in a Direction oblique to the Plane of the Orbit, by Reaſon of the Motion compounded of the Motion of the Light and that of the Spectator.

2644. Let us ſuppoſe the Light to be mov'd along the Line E G, mak-
Plate 85. ing any Angle with the Line F G, in which the Spectator is carried,
Fig. 3, 4. whom we ſuppoſe at F; let the Velocity of the Spectator be to the Velocity of Light, as F G to E G. Whilſt the Spectator runs through F G, the Light moves through E G; and the Particle of Light, which is at E, when the Spectator is at F, enters the Eye, when it comes to G; but the Direction of the Light with regard to the Eye makes the Angle E F G with the Line F G. For if we ſuppoſe the Line F E drawn, and carried with a Motion parallel with the Eye, ſo as with reſpect to that to be at Reſt, whilſt the Eye is mov'd, the Light will enter into the Eye in this Line; for when the Eye ſhall be at *f*, in the Middle Point between F and G, the Line mov'd will cut E G in it's Middle Point *g*, which the Particle of Light has arriv'd at, which is alſo the Middle Point of the Line mov'd *f e*; therefore the Point of Light, which was at E, at the End of the Line E F, has come to the Eye along *e g*; and will enter the Eye in this Direction.

2645. Now let the Angle E G F be a right one, and let E G be to
Fig. 3. F G, as the Velocity of Light to the Velocity of the Earth in it's Orbit, and E F G will be the Angle, which the Direction, according to which the Light enters into the Eye, makes with the Plane, in which the Earth moves round the Sun.

2646. If the Earth be at B, it moves in the Direction of the Tangent
Pl.85.F.5. to the Orbit in this Point; that is, if we bring the Spectator to
* 2642. S *, the Direction of the Motion of the Earth is along S C; and, making the Angle *a* S C equal to the Angle E G F of the third Figure, the Line S *a* will repreſent the Line, along which the Spectator wou'd ſee the Star. In the ſame Manner when the Earth ſhall be at D, the Spectator being brought to S, will ſee the Star along S *c*, ſuppoſing the Angles P S *c* and P S *a* to be equal;

and

and this Line S*a*, or S*c*, wou'd, by it's Revolution round P S, deſcribe a Cone, whoſe Baſe in the Heavens wou'd be a Circle run through by the Star in a whole Year, with it's apparent Motion: Let us ſuppoſe this Circle to be alſo repreſented by *a b c d*, ſuppoſing the Letters to be as in the ſecond Figure.

If the Star ſhou'd not be in the Perpendicular P S to the Plane of the Ecliptick, but if the Line P S ſhou'd be inclin'd to this Plane, the Lines which determine the apparent Motion of the Star in the Heavens, wou'd make Cones, as in the Caſes explain'd *; but theſe wou'd now be oblique, and in each Caſe the apparent Way of the Star in the Heavens wou'd be determin'd according to what has been explain'd; but it wou'd be elliptical, and the greater Axis of the Ellipſe * wou'd be equal to the Diameter of the Circle *a b c d*, of the ſecond Figure, or the fifth; ſo that from the Ellipſe being known there is given the Circle, which the Star wou'd deſcribe, if it ſhou'd be in the Perpendicular to the Plane of the Ecliptick. 2647. Plate 85. Fig. 6, 7. * 2641.2646. * 625.

It is to be determin'd from Obſervations, whether the Stars do deſcribe ſuch Ellipſes; and in theſe are great Difficulties, which nevertheleſs the Reverend Mr. *Bradley* has overcome by his Labour, and incomparable Induſtry. 2648.

Nothing can be immediately determin'd concerning the elliptical Motion which has been mention'd. The Diſtance of a Star from the Pole of the World, at different Times of the Year, muſt be meaſur'd; and from the different Diſtances, the elliptical Motion muſt be determin'd by Computation, attending to the Motion of the Pole itſelf in the Time, which paſſes between the Obſervations; for the Pole moves in a ſmaller Circle, in which it runs through one Degree in ſeventy Years. 2649.

Mr. *Bradley* having taken all neceſſary Cautions obſerv'd many Stars at different Times of the Year, and immediately diſcover'd that their Diſtances from the Pole of the World varied; and he perceiv'd that this Variation cou'd not be attributed to the Nutation of the Pole; for he examin'd two Stars equally diſtant from the Pole, but oppoſite in ſuch Manner, that one ought to have receded from the Pole, ſo much as the other approached towards it, if the Pole itſelf had been mov'd. But this did not happen; the Alteration with reſpect to one Star was double of that, which the other Star underwent, always ſetting aſide the Motion of the Pole from it's Revolution which has been mention'd. 2650.

2651. This diligent Obſerver deduc'd from Obſervations, that the Stars, at ſtated Times, receded from the Pole of the World, and approached towards it, according to the Law which the above-
* 2647. mention'd Motion in an Ellipſe requires * : And indeed in ſuch Curves, from which with regard to all is deduc'd the Motion in
Fig. 4, 5. the ſame ſmall Circle, as *a b c d*, when the Stars are brought to the
* 2647. Perpendicular at S to the Plane of the Ecliptick *; and the Diameter of the Circle with regard to all the Stars is 40″ ½.

2652. But when this appears from Obſervations, theſe eaſily ſhew, to which of the two Cauſes above-mention'd we ought to attribute
* 2641.2646. the Motion of the Star *. For if the firſt ſhou'd take Place, the
Fig. 2. Motion of the Star wou'd be from *a* to *c*, whilſt the Earth runs
* 2641. through the Part A B C of it's Orbit *; but this diſagrees with Obſervations, and this Cauſe does not take Place. But this Alteration in the Situation of the Star, according to Obſervations, ob-
Fig. 5. tains whilſt the Earth runs through the Part of it's Orbit B C D,
* 2646. as the ſecond Cauſe requires *.

2653. If the two Cauſes ſhou'd take Place together, the Arch, run through by the Earth, wou'd differ from the two above-mention'd; and the Concourſe of the two Cauſes alſo diſagrees with Obſervations; unleſs we wou'd attribute to the firſt Cauſe, ſome ſmall Matter, that is not ſenſible in Obſervations. From all which we deduce the following Concluſions.

2654. 1ſt. That only the ſecond Cauſe takes Place here; and that the Diſtance of the Stars is ſo great, that the Diameter of the Earth's
* 2642. Orbit has no ſenſible Ratio to it *.

2655. 2dly. That the Angle F E G, in the Triangle above-mention'd *, is 20″ ¼; and therefore there is the Ratio of 10210 to 1, between
Fig. 3. E G and F G, that is, between the Velocity of Light and that of
* 2645. the Earth's in it's Orbit. Whence it ſhou'd follow, that Light comes to us from the Sun in eight Minutes and an half.

2656. 3dly. That Light comes from all the Stars with the ſame Velocity; for the Angle E F G is the ſame with reſpect to all. Whence it follows (if we ſuppoſe, that the Stars are not all at equal Diſtances from us, as many Arguments ſhew) that the Motion of Light, whilſt it paſſes through immenſe Spaces to our Atmoſphere, is equable.

2657. But we muſt attend to this, that the ſmall Differences cannot be perceiv'd; and no one can deny, that, in the Meaſure of a ſmall Angle, whatſoever Care we take, there may eaſily be an Error of one Second; and therefore, although we ſaid that the firſt Cauſe was

was to be rejected *, we do not deny that the Stars from this Cauſe * 2652.
deſcribe a ſmall Circle perhaps, whoſe Diameter is equal to 1 ″, or exceeds this Meaſure a little.

We have in this Chapter examin'd what relates to the Velocity 2658.
of Light, with the greater Care, and the more clearly; becauſe all that is demonſtrated in the following ones, depends upon this Foundation; *viz.* that the Motion of Light is ſucceſſive, and that it may be accelerated, and retarded, in the paſſing of Light from one Body to another.

CHAP. II.

Of directing the Sun's Rays.

THE Motion of the Rays being demonſtrated, we muſt en- 2659.
quire into the Properties of them, that we may deduce Phenomena from them. For this Purpoſe the Sun's Rays muſt be conſider'd. But in this Examination we meet with two Inconveencies, of the Method to remove theſe I ſhall ſpeak in this Chapter. The Inconveniencies are theſe, 1. The Obliquity of the Rays; 2. The continual Motion of the Sun.

From the Obliquity of the Rays it follows, that ſome Experiments can only be made at certain Hours; and others can never be made in a Place, otherwiſe convenient, although it be large enough, and expos'd to the Sun's Rays, a great Part of the Day. By the Motion of the Sun the Direction of the Rays is continually alter'd, ſo that the Conſtitution of the Machines, made uſe of in the Experiments, muſt be continually alter'd.

By making uſe of the following Machine, both Inconveniencies are remov'd.

AN HELIOSTATE,

Whereby the Sun's Rays are fix'd.

This Machine conſiſts of two principal Parts, each of which 2660.
conſiſts of many ſmaller Parts. The firſt is a plane metallick Spe- Plate 83.
culum, ſupported by a Stand, the other is a Clock which directs the Speculum.

We make uſe of a metallick Speculum, becauſe there is a dou- 2661.
ble Reflection in a Glaſs one. The Magnitude and Figure of it

are not material; mine is rectangular, four Inches long and three broad.

This is put into a wooden Frame, which is ſurrounded with wooden Rulers, cut in, whereby the Speculum is retain'd.

2662. To ſuſtain this, without hindering it's Motion, to the ſaid wooden Frame, behind, is applied the Braſs Plate *a a*, whoſe Ends, being bent, are faſten'd to the Wood ſideways.

2663. This Speculum S is ſuſpended by the Handle A A, ſmall Screws being put through Holes in the End of it, which go into the Ends *a*, *a*, of the ſaid Frame, and whoſe Parts, which are in the Holes of the Handle, are cylindrical, ſo that the Speculum turns freely upon it's Axis, which, if it were made ſenſible, wou'd paſs along the Surface of the Speculum.

2664. The Handle is join'd to the Cylinder C, whoſe Axis, if it were continued, wou'd concur with the middle Point of the ſaid Axis of the Revolution of the Speculum.

2665. To the ſame Point anſwers the Tail D E, which is join'd perpendicularly to the hind Part of the Speculum. This Tail is cylindrical; and is made of a Braſs Wire, which is ſtrait, firm, and whoſe Diameter is about a ſixth Part of an Inch.

2666. The Cylinder C is put upon the wooden Stand P, whoſe upper Part is repreſented by itſelf; whilſt this is done, the Iron Cylinder *e*, whoſe Surface is ſmooth, goes into a Cavity in the Cylinder C, which is of Copper; by which Means this turns freely about it's Axis, ſo that, by the Motion of the Tail D E, the Poſition of the Speculum is very eaſily alter'd as you pleaſe.

2667. This is rais'd, and depreſs'd, by Means of the three Braſs Screws B, B, B, which are turn'd with a Key, and go through a Plate of the ſame Metal, which is applied to the Bottom of the Stand for that Purpoſe; and which ſtands out in three Places, to receive the Screws.

2668. If the Speculum is to be rais'd higher, as may eaſily be done, we put the Speculum together with it's Stand, upon a ſmall Board, which has low Feet, and is made for that Purpoſe.

2669. The other Part of the Machine is a Clock, as has been ſaid above. This is repreſented at H; the Index performs it's Revolution in twenty four Hours.

2670. The Plane of the Clock is inclin'd to the Horizon, according to the Inclination of the Equator in the Place, where the Machine is made uſe of; that is, in this our City of *Leiden* is $37^{\circ}\ 49'$.

But this Machine may be made uſe of in other Places, whoſe Latitudes differ one or two Degrees from this Place, as will appear *. 2671. * 2675.

The Clock is ſuſtain'd by the Copper Pillar F G; this conſiſts of two Parts, which are joined by the Screws *d*, *d*, between which, as in a Sheath, is mov'd an Iron Plate, in the Middle of which there is a Slit, through which the ſaid Screws *d*, *d*, paſs. This Plate is join'd faſt to the lower Plate of the Clock itſelf, which is rais'd and depreſs'd by this Method, and faſten'd by the Screws *d*, *d*. It may alſo be rais'd higher by the Screws I, I, I, which go through the thick Copper Plate L L M, upon which the Pillar F G ſtands. 2672.

The extreme Parts of this Plate L, L, are terminated in ſuch Manner, that *b c* and *c b* make one right Line, through which we ſuppoſe a vertical Plane to paſs, this will be perpendicular to the horizontal Lines, which may be drawn on the Plane of the Clock; ſuch as are *f g*, *h i*. 2673.

The Machine is ſo order'd, that the Plane of the Clock may have the Inclination beforemention'd *, when the Plane L L M is horizontal; in which Situation it is eaſily plac'd by Means of the Screws I, I, I, by Help of the Plumb Line Q, whoſe Point ſhou'd anſwer to the Point *o*, which is mark'd upon the Surface L L M. 2674. * 2670.

If the Machine were to be us'd in another Place, whoſe Latitude differ'd from that, for which the Machine was conſtructed *, another Point as *o* wou'd be to be mark'd, in which Caſe the Plane L L M wou'd be inclin'd to the Horizon. 2675. * 2671.

The Axis of the Wheel, which moves the Index, is pretty thick, and is perforated cylindrically; but the Cavity inclines a little to a conical Figure; for towards the Bottom it is ſomewhat narrower. 2676.

The Index itſelf is repreſented at O N; this is of Braſs, and it's Tail *p q* exactly fills the Cavity mention'd laſt, into which it is thruſt tight, that it may ſtick, and, that the Wheel may carry the Index with it as it moves; whoſe Situation may yet be alter'd, and ſet to any Hour. 2677.

This Tail has alſo a cylindrical Hole, and through this paſſes the ſmall Braſs Wire *l d*, which remains in any Situation, whilſt it is rais'd, or depreſs'd. 2678.

At the End O of the Index there is a ſmall Cylinder *n*, which is perforated cylindrically. 2679.

The

2680. The Length of the Index is meaſur'd in the Line, perpendicular to *l d*, drawn from the Axis of the Cylinder *n* to the Axis of the Wire *l d*. In my Machine this Length is ſix Inches.

2681. The Iron Tail *t* of the Piece T goes into the Cavity of the Cylinder *n*; this Tail exactly fills the Cavity, but yet moves freely in it.

2682. Between the Legs of the Piece T, the ſmall Pipe R may be ſuſpended at different Heights, through which the Tail D E of the
* 2665. Speculum may be mov'd freely *, which fills the Pipe very exactly.
† 2663. This ſmall Pipe is ſuſpended, as was ſaid of the Speculum †. The ſmall Screws *r*, *r*, paſs through the ſaid Legs, and the Ends of them go into the Parts *m*, *m*, of the Pipe, and remain there: Then the Pipe turns freely about the Axis which paſſes through *m m*; for the Parts of the ſmall Screws are cylindrical, which anſwer to the Holes in the Legs of the Piece T.

2683. When the Machine is to be fix'd, we make uſe of another Machine which we ſhall call a *Placer*.

2684. The Cylinder C together with it's Speculum is remov'd from the Stand P, upon which is plac'd the Braſs Pillar V X. This ſticks tighter to *e* than the Cylinder C, that the Pillar may keep it's Place, whilſt the Machine is ſettled.

2685. Upon the Head X the Ruler Y Z moves round a Center, ſo that it may be inclin'd to the Horizon as you pleaſe, and keep it's Poſition. The Length of the Arm Y X is determin'd at Pleaſure. The Arm X Z is of a peculiar Conſtruction, and a certain Length.

2686. To the ſaid Ruler, which is not extended beyond *y*, there are applied to others, as *x* Z, between which the firſt is inclos'd: Theſe are join'd at Z, and alſo cohere by Means of the Screws *z*, *z*, which paſs through a Slit in the firſt Ruler. On this Ruler is mark'd the ſmall Line *v s*, whoſe Length is equal to nine hundredth
* 2680. Parts of the Length of the Index *; and which is divided, in the Manner which will be mention'd preſently.

2687. The Arm X Z is equal to the Length of the Index *, if it be
* 2680. meaſur'd between the Center of Motion at X and the End Z, when the End *x* of the outward Ruler, agrees to *v*, where the Diviſions of the ſmall Line *v s* begin.

2688. The Diviſions of this ſmall Line are unequal, and determine the Length of the Arm at different Times of the Year, by applying *x* to the Diviſion, which anſwers to the Day, in which the Machine is us'd.

But

But in order to mark the Diviſions, we ſuppoſe the Length of the Arm * to be divided into a thouſand equal Parts, that is, *v s* into ninety Parts; but the Diſtances from the Point *v* are ſet down in the following ſmall Table. 2689. * 2680. 2690.

21. Mar.	1. Mar.	21. Fe.	11. Fe.	1. Fe.	21. Ja.	11. Ja.	21. Dec.
0.	8.	17.	32.	47.	64.	77.	90.
21. Sept.	11. Oct.	21. Oc.	1. No.	11. No.	21. No.	1 Dec.	21. Dec.

On the oppoſite Side of the Ruler, there is alſo drawn a ſmall Line, which accurately anſwers to *v s*, whoſe Diviſions are contain'd in this ſecond ſmall Table. 2691.

21. Mar.	11. Ap.	21. Ap.	1. May	11. May	21. May	1. Jun.	21. Jun.
0.	11.	22.	36.	51.	66.	79.	90.
21. Sep.	1. Sep.	21. Au.	11. Au.	1. Au.	21. Jul.	11. Jul.	21. Jun.

Theſe Things being thus order'd, to fix the Machine, it is put upon a Plane that is horizontal, or nearly ſo. 2692.

Firſt we join the Placer * to the Stand P †, which we raiſe as much as is neceſſary *, that the Ruler Y Z being reduc'd to a juſt Length †, which we turn at Pleaſure, and incline, in every reſpect, that is with reſpect to the Place, and Direction, may agree to the Sun's Ray, which we undertake to fix. 2693. * 2683. † 2684. * 2667. 2668. † 2688.

We ſo order the other Part of the Machine, that the Lines *b c*, *b c*, may agree to a Meridian Line, which has been drawn on the Plane *; and it is ſo diſpos'd by Means of the Screws I, I, I, that the Plumb-Line Q may anſwer to the Point *o* †. 2694. * 2692. † 2674.

The Index N O is turn'd *, that the Sun's Rays may paſs directly through the Pipe R †, which is turn'd, and inclin'd, as is requir'd. The Braſs Wire *l d* * is then rais'd or depreſs'd, that the Shadow of the End of it *l* may paſs through the Middle of the Pipe. 2695. * 2677. † 2682. * 2678.

This whole Part is mov'd to the Placer, which is order'd as has been ſaid before *. But the Clock is ſo mov'd towards the Placer, and rais'd, that the End *l* of the Braſs Wire *l k* may agree to the End Z of the Ruler Y Z. 2696. * 2693.

We muſt continually have regard to the Plummet Q, that it may always anſwer to the Point *o*; we muſt alſo take Care, that, after the Clock is mov'd, the Sun's Rays and the Shadow of the Point *l*, may paſs through the ſmall Pipe R, as before, that the Poſition with reſpect to the Meridian may not be diſturb'd.

The

2697. The Pillar V X with it's Ruler Y Z is remov'd, the Stand P being left in it's Place, on which the Cylinder C, with it's Speculum, is put. The Piece T is taken out of it's Place, that the Tail D E of the Speculum may be put through the Pipe R; when the Piece T is put in the ſame Place again, every thing is ready.

2698. Then the Rays reflected from the Middle of the Speculum, to which all the other Rays, reflected from the Speculum, are parallel, agree, as to Place, and Direction, with the Poſition which the Ruler of the Placer had; and whilſt the Tail of the Speculum is mov'd, as the Clock moves, whoſe Index follows the Sun, it's Situation is alter'd with reſpect to the Sun; but the Ray, reflected from the middle Point of the Speculum, remains fix'd.

2699. If, the Index N O being taken away, we ſubſtitute the Index K, the Machine may be us'd as a common Clock.

2700. The Experiments concerning Light muſt be made in the Dark; for this Reaſon the Machine, when made uſe of in the Experiments, muſt be ſhut up in a Box or Caſe.

A BOX or CASE,
In which the Helioſtate is inclos'd.

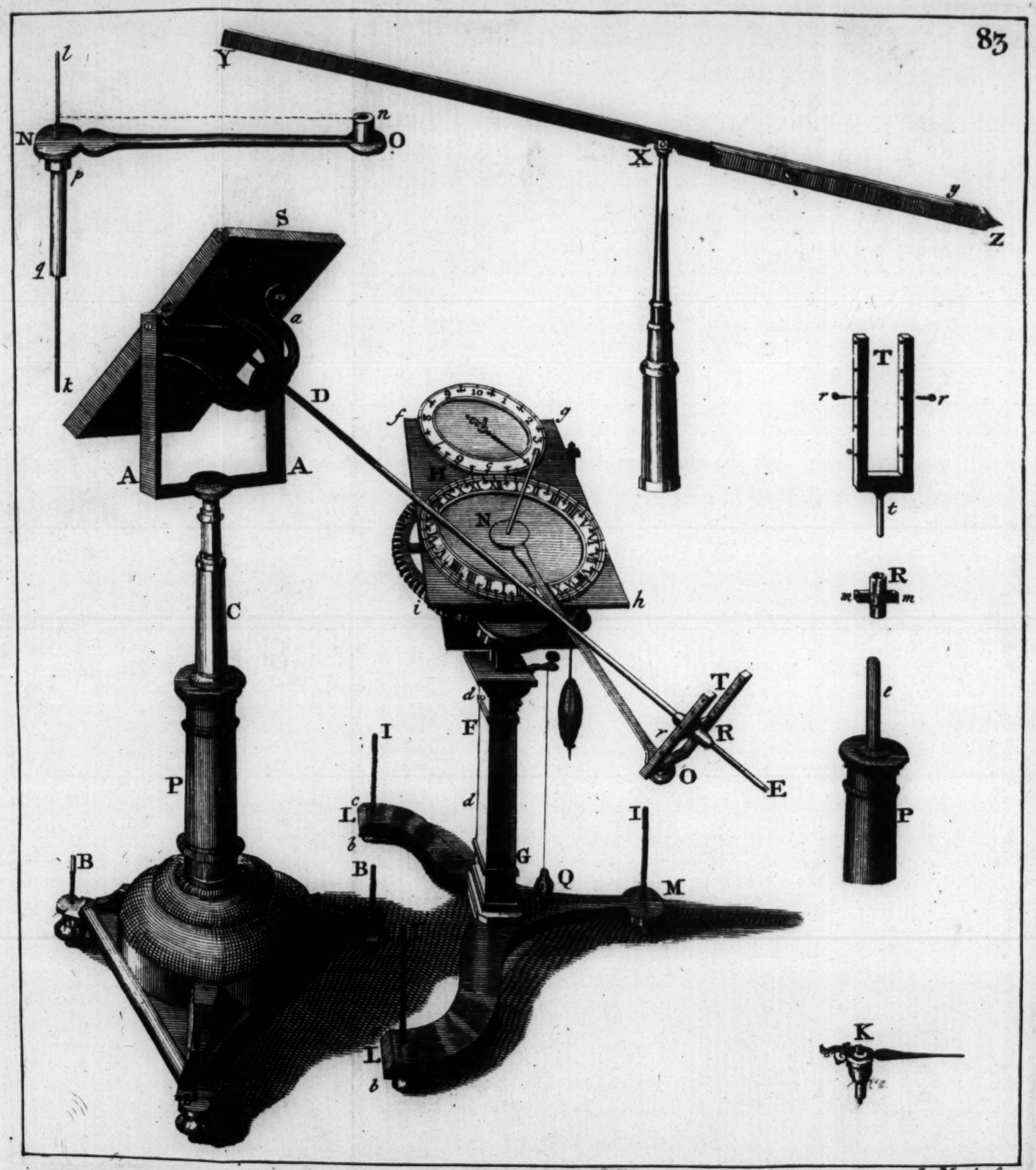
2701. The Box is repreſented at A; it ſtands upon Feet, that have
Plate 84. Rollers join'd to them, that it may be eaſily mov'd. It is open at one End, which End is mov'd to a Window, through which the Sun's Rays come freely to the Speculum.

2702. But the Box is every Way larger than the Window, that by being applied cloſe to the Wall, the Light may be hinder'd from entering into the Chamber; to this End, the Box is mov'd as near the Wall as poſſible, and the Screws C, C, which are faſten'd to the fore Feet, are turn'd, till they touch the Ground.

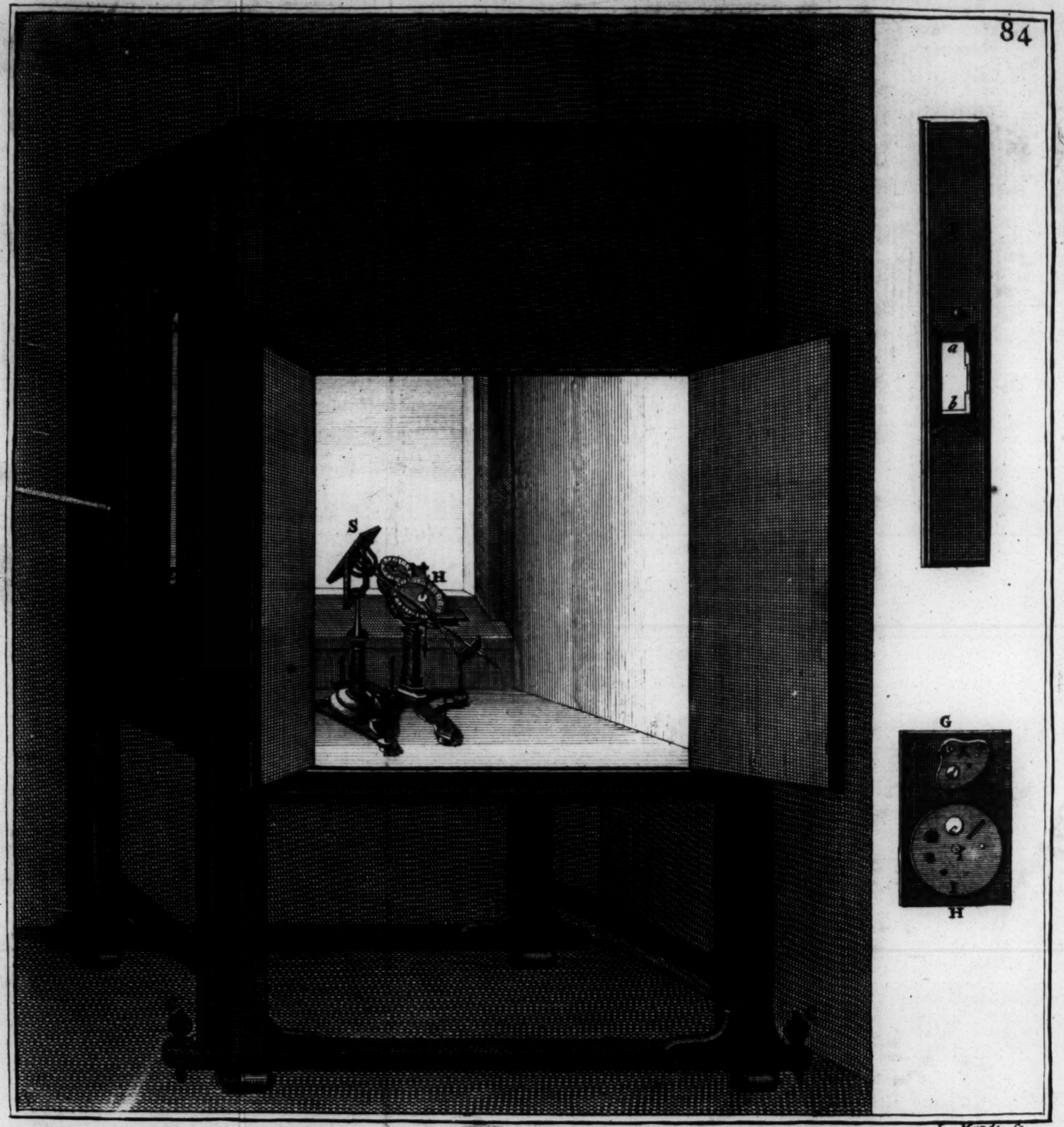
2703. The Door in my Machine is oppoſite to the Window; it might have been otherwiſe diſpos'd. We tranſmit the Rays through the fore Part B; we make choice of this, by Reaſon of the make of the Place, in which the Experiments concerning Light were made. In this Part there are two Apertures three Inches broad, and about eighteen Inches high, one of which is repreſented open at D E.

2704. Theſe are clos'd, on the Outſide, by Pieces of Wood, which are moveable between wooden Rulers. Each Piece ſerves either Aperture, that they may be chang'd. One of them F is three Foot long, and has a Hole in it's Middle. The Aperture *ab* is five Inches long, and two broad.

This


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b
B
G
Q
M
B
L
b
K

T. Mynde fr.



J. Mynde Sc.

This is clos'd by the Copper Plate G H, in which there are two Holes, *c*, *d*; the Diameter of that is two Thirds of an Inch, the Diameter of this is leſs. Theſe Holes are ſtopp'd by the Plates I and K, which are applied to the firſt Plate G H, and are moveable about the Centers *i* and *k*: the Magnitudes of the Holes may alſo be varied, by turning the laſt Plates, as the Figure ſhews. 2705.

The Board F is hollow'd behind, in order to receive the object Glaſs of a Teleſcope of ſixteen, twenty, or five and twenty Feet, according to the Magnitude of the Place, in which the Experiments are made; the Center of this Glaſs ought to anſwer to the Center of the Hole *c*. 2706.

This Board F is pretty long, the Holes of the ſmall Plate may anſwer to any Part of the Aperture of the Box, the other Part of the Aperture remaining ſhut. For this Reaſon the ſecond Board is ſhorter, it is ſufficient if the Aperture be clos'd with this. Theſe Boards are faſten'd by the Screws M, M. 2707.

We have ſhewn how the Box is to be applied to the Window *; but this cannot be done thus, if we wou'd make the Experiments in the Hours, in which the Sun's Rays enter the Window very obliquely; in this Caſe, that the Rays may come to the Speculum, the Box muſt anſwer to a Part of the Window only; the remaining Part is clos'd any other Way; I make uſe of a Curtain, to exclude all the Sun's Rays. 2708. * 2702.

SCHOLIUM.

A Demonſtration of the Effect of the foregoing Machine.

THIS Demonſtration is deduc'd from the diurnal Motion of the Sun; therefore thoſe, who are unacquainted with the Laws of this Motion; may paſs over this Scholium, till they read in the following Book what relates to this Matter. 2709.

Let S be the middle Point of the Speculum; S A the reflected Ray, which is to be kept in this Situation, taken at Pleaſure; let the incident Ray, in any Moment whatever, be B S. When I ſpeak of the Reflection of Light, I ſhall demonſtrate, that theſe two Rays are in a Plane, perpendicular to the Plane of the Speculum, and that the Line perpendicular to this Plane at S, divides the Angle B S A into two equal Parts. Therefore taking S A, S B equal, and drawing B A, if this be divided into equal Parts at R, S R will be the ſaid Perpendicular *; and this being continued S*r* ſhews the Poſition of the Tail of the Speculum *, in the Caſe which we are conſidering. 2710. Pl. 85. F. 8. * 3. El. 3. * 2665.

If the incident Ray be CS, we diſcover the Poſition of the Tail of the Speculum in this Caſe after the ſame Manner, taking SC equal to SA, and drawing AC; for if we divide this into two equal Parts at E, and ES*e* be drawn, S*e* will determine the Poſition of the Tail of the Speculum.

In like Manner, ſuppoſing DS to be the incident Ray, let DS be equal to SA, and let DA be divided into two equal Parts at I; if IS*i* be drawn, S*i* will ſhew the Poſition of the Tail of the Speculum.

After the ſame Manner, when the incident Ray is alter'd at Pleaſure, is diſcover'd the Poſition of the Speculum, that the reflected Ray may remain.

2711. The Sun in it's diurnal Motion deſcribes the Equator, or a Circle parallel to it; we conſider this laſt Caſe.

Drawing Lines from all Points of this Circle to the Center of the Earth, theſe will make the Surface of a right Cone, which alters every Day; we take into Conſideration any one of theſe Cones.

2712. Any Point on the Surface of the Earth may be taken for it's Center, by Reaſon of the immenſe Diſtance of the Sun; as is done in Dialling.

2713. Therefore let S be the Center of the Earth; the Rays SB, SC, SD, together with all the intermediate ones, will make a right Cone; all theſe being continued, and taking S*b*, S*c*, S*d*, equal to one another and the firſt Lines, and therefore to SA, the Points *b*, *c*, *d*, will be in the Circumference of a Circle, whoſe Plane is parallel to the Plane of the Equator.

2714. Continue AS to *a*, and make S*a* equal to AS; and drawing the Lines *da*, *ca*, *ba*, the Line *da* will be parallel and equal to AD, by Reaſon of
*14,15, El.1. the Triangles ASD and *a*S*d*, which agree in every Thing *; and the Line IS continued will cut *ad* in the middle Point *i*. In the ſame Manner *e* and *r* divide the Lines *ca*, *ba*, into equal Parts.

2715. Theſe Lines *da*, *ca*, *ba*, with the others, which are drawn from Points of the Circumference *dcb* to *a*, make the Surface of an oblique Cone. If this be cut by a Plane, parallel to it's Baſe, the Section will be a Circle; but if the Section paſſes through one of the Points, as *i*, *e*, *r*, it will paſs through all, which eaſily appears; and all theſe Points, with the like Points, are in the Circumference of a Circle, whoſe Plane is alſo parallel to the Equator.

2716. Divide S*a* into two equal Parts at *l*; and draw *il*, *el*, *rl*, theſe will be parallel to the correſponding Lines, paſſing through S; *rl* is parallel to *b*SB, for the Sides S*a*, *ba*, of the Triangle S*ba* are biſected at *l* and *r*.

So likewiſe *el* is parallel to *c*SC; and *il* is parallel to *d*SD; and ſo
* 2714. of the others. But as *b*S is equal to S*a* *, *rl* will be equal to *la*, or *l*S.

2717. When the Direction of the Sun's Rays is BS, or *lr*, which are pa-
* 2716. rallel *, the Point S reflects the Ray along SA, when the Tail of the
† 2710. Speculum paſſes along *r* †. This Tail ought to paſs along *e*, if the Direction

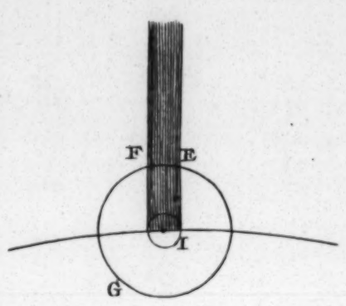


Fig. 1.

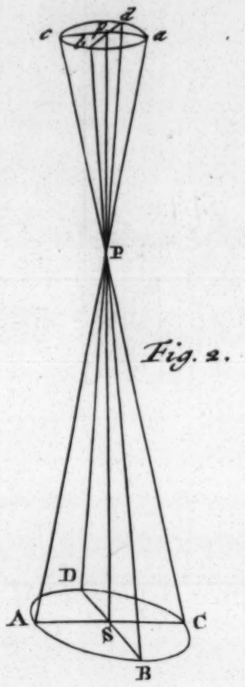


Fig. 2.

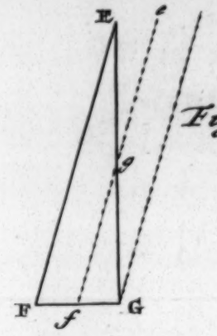


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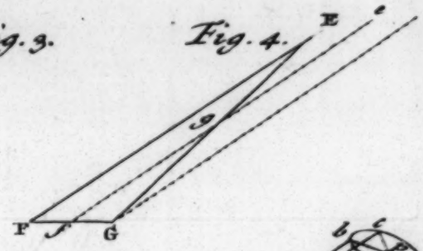


Fig. 4.

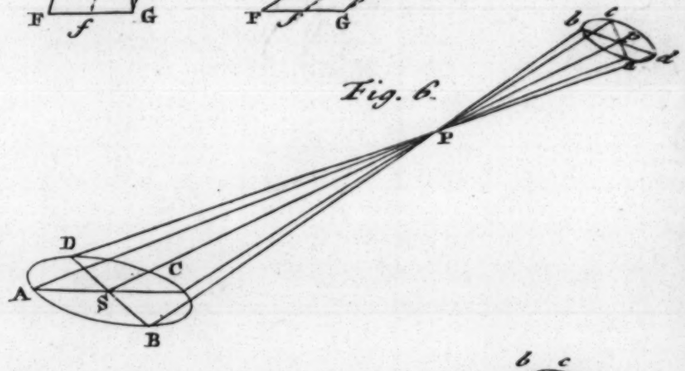


Fig. 6.

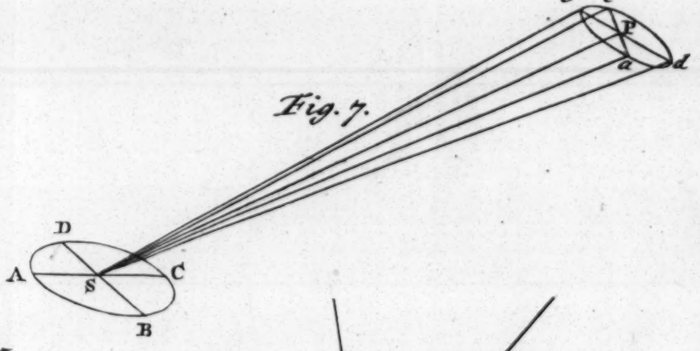
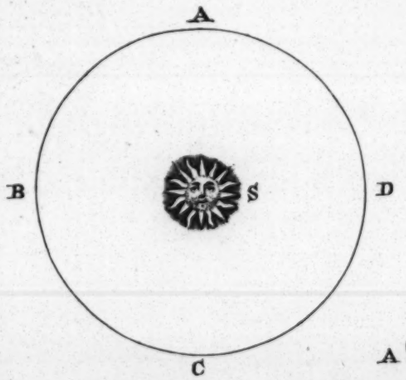


Fig. 7.



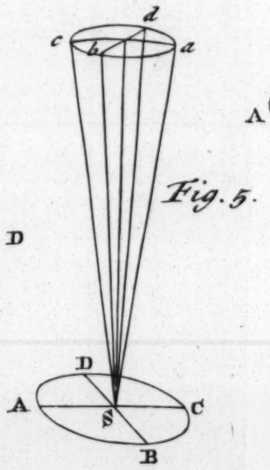


Fig. 5.

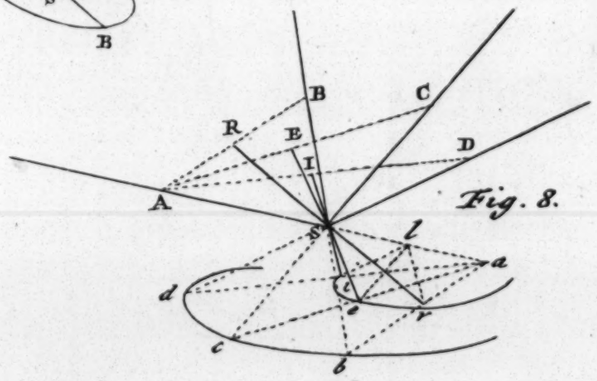


Fig. 8.

rection of the Rays be *le* parallel to CS; if they be directed along DS and *li*, the Tail muſt be directed along *i*. If this be every where obſerv'd, SA will always be the reflected Ray.

Hence it follows, that the Ray reflected along SA remains fix'd, when the Tail of the Speculum continually concurs in the Circumference of the Circle *ier* with the Sun's Ray that paſſes through *l*. But we ſhall demonſtrate that the Machine, deſcrib'd above, performs this. 2718.

The Index of the Clock moves with the Sun, and the middle Point of the Pipe R, deſcribes a Circle parallel to the Equator, for the Pipe is ſuſpended in ſuch Manner, that the middle Point is not alter'd, by varying the Inclination of it, or turning the Piece T, that ſuſtains the Pipe *. This is the Circle, that is mark'd with the Letters *ier* in this Figure. 2719. * 2681.2682.

The Index of the Clock is ſo order'd, that, during it's Motion, the Ray of the Sun, which paſſes through the Point *l* (Pl. 83.) which is the ſame with the Point *l* in this Figure of ours, may alſo always paſs through the ſaid middle Point of the ſmall Pipe *, through which Point alſo the Axis of the Cylinder continually paſſes, which makes the Tail of the Clock; therefore the Machine will perform all, that is requir'd *, if the Center of the Speculum be well order'd. * 2695.2669. * 2697.2718.

In the Delineation of the Machine, and in the preſent Figure, the Point *l* is marked with the ſame Letter, and in this S repreſents the middle Point of the Surface of the Speculum, which Point remains unmov'd in the Agitation of the Speculum. Therefore we muſt demonſtrate that *l* in this Figure is conſtituted with reſpect to S, as *l* is in that with reſpect to the Center of the Speculum. 2720.

In both Figures the two Points are in the reflected Ray continued *: The Diſtance S*l*, in this laſt Figure, is equal to any Line as *li*, or *le* *; theſe Lines make an Angle with the Plane of the Circle *ier* equal to the Declination of the Sun, and theſe Lines, and therefore S*l*, are equal to the Secant of this Angle, when a Circle is made uſe of, whoſe Ray is equal to the Semidiameter of the Circle *ier*; this Semidiameter anſwers to the Length of the Index *, and the Ruler of the Placer is divided in ſuch Manner †, that the Length of the Part, which meaſures the Diſtance between the Center of the Speculum and *l* *, is always equal, according to the Time given, to the Secant of the Declination of the Sun, at that Time, the Ray of the Circle being given equal to the Length of the Index; to this Secant is alſo equal the Diſtance between *l* and the middle Point of the ſmall Tube which follows from the Direction of the Sun's Rays *. Therefore every Thing anſwers in the Figures, which remain'd to be demonſtrated. * 2693.2697. 2714. * 2716. * 2680.2619. † 2690.2691. * 2688. * 2695.

When the Sun is in the Equator the Point *l* coincides with the Center of the Circle *ier*. When it is in the Southern Signs, *l* is depreſs'd below the Plane of the Circle *ier*; for this Reaſon the Legs of the Piece T are pretty long, that we may in the Winter raiſe the Pipe, through which the Tail of the Speculum paſſes. 2721.

CHAP. III.

Of the Inflection of the Rays of Light.

2722. WE have ſhewn before that Fire is attracted by Bodies *;
* 2398. this appears plainly in the Sun's Rays, which are bent towards Bodies, when they paſs along at a ſmall Diſtance from the
2723. Bodies. This ſhews that *the Rays are* driven towards Bodies, and
* 73. *attracted by Bodies* * with ſome Force.

2724. The ſaid *Attraction* is ſubject to the ſame Laws as that, which
* 75. obtains between the ſmall conſtituent Particles of Bodies *. *In Contact* it *is very great*; in this Caſe the Light joins itſelf to the Particles of Bodies, as has been obſerv'd in general with regard to
* 2397. Fire *, which appears directly from daily Obſervations made on Light; for Bodies, which are illuminated with the Sun's Rays, do not reflect, or tranſmit them all, but many are extinguiſh'd in the
* 2421. Bodies themſelves, and communicate Heat to them *.

2725. The *Attraction* of which we are ſpeaking, *ſuddenly decreaſes* as we recede from the Body, *and extends itſelf to a* ſmall *Diſtance*,
2726. which is yet *not altogether inſenſible*; *at a greater Diſtance it is chang'd into a repellent Force, whereby the Rays* are bent, *and recede from Bodies*; *which Action, as you recede from a Body, is alſo diminiſh'd.*

2727. According to this Law the Rays are differently bent, as they
Plate 86. paſs at a ſmall Diſtance from the Angle, which the Surfaces of a
Fig. 1. Body make. Let C be an Edge, which ſuch an Angle makes, which we ſuppoſe Acute, that the Effect may be the more ſenſible. A Ray of Light conſiſting of many Rays parallel to one another, when it paſſes near the Edge, is diſpers'd; that Ray of thoſe, into which the firſt Ray is divided, which paſſes at the leaſt Diſtance, is attracted the moſt ſtrongly; A B is bent towards F.

As we recede from C, the Deflection is diminiſh'd, and the Ray H I paſſes on in a ſtrait Line. If the Diſtance is increas'd there is a Repulſion, which ſuddenly increaſes, and again decreaſes; for, when the Repulſion obtains, we find that it is greater at a leſs than at a greater Diſtance, a Ray, as D E, is bent towards G.

Among the Experiments, which belong to this Matter, I ſhall ſelect thoſe, from which the ſaid Properties of Light manifeſtly follow.

A MA-

A MACHINE,

Whereby Experiments concerning the Attraction, and Repulſion, of Light, are made.

The Plate A BE is of Braſs; to this are applied the Rulers BF, EG, made of the ſame Metal, between which the Steel Plate I is moveable, which is thruſt forwards, and drawn backwards, by Means of the Screw C; a like Steel Plate H is applied to the Plate ABE, and faſten'd by Means of the ſmall Screws *n*, *o*. 2728. Pl.86.F.2.

Theſe Plates cover a ſquare Aperture in the Plate ABE; the Sides of this Square are equal to half an Inch. The Surfaces of the Plates I and H, which touch the Plate, are plane; and the Plates are ſo cut, that each has an Edge *a b*, which are more or leſs ſeparated, or join'd together, by turning the Screw C. 2729.

The Hole, through which the Screw *n* goes, is ſomewhat wider, that the Plate H may turn a little about the Center *o*, and that it's Edge may be inclin'd a little to the other; in this Poſition it is fix'd by the Screw *n*, and both the Edges can come together only in one Point. 2730.

The Plate H is ſometimes applied to the oppoſite Surface of the Plate ABE, whoſe Thickneſs is equal to about a twelfth of an Inch; it is faſtened by Means of the Screws *n*, *o*, which go into the ſame Holes of the Plate ABE. The Poſition of the Plate H is inverted, that the ſame Surface of it may touch the Braſs Plate. 2731.

In the Repreſentation of the Machine the Dimenſions are reduc'd to an half.

To the Board T, which is here reduc'd to a ſixth Part of it's Dimenſion, we apply the Plate mention'd *, and faſten it by Means of Screws. We repreſent the oppoſite Surface of the Board, that the Aperture L may appear, which is an Inch high, and a little broader, which the Plate itſelf covers: The Board ſtands upon Feet that it may keep it's vertical Poſition. 2732. Pl.86.F.3. * 2728.

In the following Experiments we make uſe of the Helioſtate *, which is the moſt convenient; but as all, who may be willing to make theſe Experiments again, and conſider their Circumſtances, cannot make uſe of ſuch a Machine, either by Reaſon of the want of Skill in the Workmen that make them, or for ſome other Reaſon, I will alſo ſhew how theſe Experiments may be made without the Helioſtate. And I ſhall obſerve this Method, *viz.* 2733. * 2660.

When any Thing peculiar is to be obſerv'd in an Experiment, made without the Helioſtate, I ſhall make mention of it.

Experiment 1.

2734. We have Occaſion for an horizontal Ray in this, and the following Experiment; according to what is explain'd in the laſt Chapter, we fix the Helioſtate in ſuch Manner, that ſuch a Ray may paſs through that Hole of the Plate, in the Side of the Box *, * 2705. which may be narrow'd moſt.

2735. If we wou'd make the Experiment without that Apparatus, and Pl.89.F.4. remove only the firſt of the Inconveniencies mention'd *, we * 2659. ought to fix in the Window, when ſhut, a Plate, like that men- † 2705 tion'd †, that the Light may enter in through a Hole, whoſe Magnitude may be alter'd, as before. We make uſe of a Hole in this Experiment, whoſe Diameter is about a Quarter of an Inch. We reflect the Ray with a plane, metallic Speculum; the Speculum is ſuſtain'd by a Tripod, like that, which is us'd in meaſuring of Land, and on which is put a Cylinder, which has a Ball that moves in it, whereby the Speculum may be turn'd any Way. We ſo diſpoſe this, that the reflected Ray may be horizontal.

2736. This Ray is directed ſo that it may paſs through the Aperture L * 2732. of the Board F *, which is plac'd at the Diſtance of ſix or ſeven Inches from the Window, and through the Aperture in the Copper Plate, join'd to the Board, ſo that it may fall on the Steel Plate ap- * 2728. plied to this Copper Plate *.

† 2729. The Edges of the Plates † are plac'd parallel to one another, and between theſe there is left a Diſtance of about a tenth of an Inch. The Light paſſes between the Edges, and falls upon white Paper, plac'd at the Diſtance of about three Foot from the Board T; the Rays, which paſs at the Mid-way between the Edges, make a white Spot, on both Sides of which the Light extends itſelf like the Tail of a Comet; which clearly demonſtrates the Inflection of the Rays, ariſing from the Attraction as they paſs along near the Edges.

The Diſtances, which have been mention'd, of the Board T, and the Paper, may be varied.

2737. In this Experiment the Repulſion of Light does not appear; becauſe the Light that is repelled, is mix'd with that, which paſſes on directly; but this is made manifeſt by the following Experiment.

Expe-

EXPERIMENT 2.

Things remaining, as in the foregoing Experiment, the Edges must be gently mov'd towards one another, by turning the Screw *; then the white Space is narrow'd, and on each Side of it there appear three colour'd Borders, parallel to the Edges; of the Colours I ſhall ſpeak in the laſt Part of this Book. The Edges being brought ſtill nearer to one another, the white Space is dilated more and more, and the Borders made on both Sides by the attracted Light, are remov'd on both Sides, and the intermediate Space is at length ſo darken'd, that it is manifeſt, that none of the Light paſſes on in a right Line. 2738. * 2728.

Theſe Phenomena appear more diſtinctly, when the Aperture in the Window is narrow'd. 2739.

Whilſt the Edges are mov'd towards one another, the Rays, which are attracted by one Edge, fall into the Sphere of Repulſion of the other Edge, and are repelled; by that the firſt Inflection is increas'd, and the Lights are remov'd farther on both Sides, and the middle Space is increas'd. Therefore the Experiment demonſtrates the Repulſion; and it alſo appears that it is greater at a leſs Diſtance *. 2740. * 2726.

EXPERIMENT 3.

We alſo immediately demonſtrate, that in theſe Caſes the Actions of both Edges concur upon the ſame Rays; for if one Edge be put into a tremulous Motion, the other being at Reſt, the Light, bent on both Sides, is affected with a tremulous Motion. 2741.

We ſaid that the Diſtance, at which Light acts upon Bodies, is not altogether inſenſible *; this alſo appears in the ſecond Experiment; for if the Diſtance between the Edges be equal to a fortieth Part of an Inch, none of the Light paſſes on in a ſtrait Line, but it is all turn'd aſide. 2742. * 2725.

From the ſecond Experiment we alſo infer, that the repellent Force diminiſhes, as the Diſtance increaſes; this we have alſo affirm'd of Attraction *; which alſo is deduc'd from Experiment. 2743. * 2725.

EXPERIMENT 4.

When the Diſtance between the Edges is ſo diminiſh'd in the ſecond Experiment, that no Light paſſes between them in a ſtrait Line, if the Diſtance be ſtill diminiſh'd, the Borders diſappear ſucceſſively, 'till the Edges being join'd, no Light paſſes between them. 2744.

It

2745. It is manifeſt that thoſe diſappear firſt, which are made by the Rays, more remote from the Edges, and that thoſe diſappear laſt, that are made by the Rays that paſs along the neareſt to the Edges. But the inward Borders, which are made by the Rays leſs bent, diſappear firſt, and the outward ones laſt; which ſhews, that thoſe Rays are the moſt bent, which paſs along at the leaſt Diſtance from the Edges.

Experiment 5.

2746. The principal Phenomena, obſerv'd in the foregoing Experi-
Pl.86.F.2. ment, may be ſeen at one View only, if the Plate H be a little in-
* 2730. clin'd, in ſuch Manner, that the Edges may make a ſmall Angle *, and be contiguous at one End. Then as the Rays paſs between the Edges, we ſee at the ſame Time, what obtains at different Di-
Pl.86.F.5. ſtances; this is repreſented at Fig. 5.

2747. The Phenomena, hitherto explain'd, differ but in one Circumſtance from thoſe, which we obſerve, when the Steel Plates are ſo diſpos'd, that the Rays may not come to one Edge, without paſſing over the other.

2748. Let H be one Plate; I the other, more remote from the Hole,
Pl.86.F.6. through which the Light enters; the Phenomena are eaſily diſcover'd.

* 2723. The Rays which paſs near H, are attracted *, and repell'd †;
† 2726. the firſt are ſenſible, becauſe they are bent towards the Shadow; the others are mix'd with them, which do not paſs directly beyond the Sphere of Repulſion. The ſame Thing obtains with reſpect to the Rays, that paſs near the other Edge, and we obſerve the
* 2736, ſame Things, as were mention'd in the firſt Experiment *.

2749. If the Space, between the Edges, through which the Light paſſes, be ſo narrow'd, that there may be paſſage only for thoſe Rays, upon which the firſt Edge, namely that of the Plate H, acts, thoſe Things happen, which were explain'd in the ſecond
* 2738.2740 Experiment *; both Edges act upon all the Rays, they are repell'd by one, which are attracted by the other, which alſo immediately
* 2741. appears, if the third Experiment * be repeated in theſe Circumſtances.

2750. In the fourth Experiment * we perceive this only Difference, all
* 2744. the Borders at the Part of the hind Plate I diſappear, thoſe remaining, which are painted at the other Part.

2751. When the Space, through which the Light can paſs, is very narrow, the Light, reflected from the Edge H, as alſo all that which

which paſſes in a right Line, runs againſt the Plate I, and is intercepted; but that, which is attracted by H, and is therefore bent, paſſes through the Sphere of Repulſion of the Edge I; then no Light is bent towards I. If any of this bent Light falls into the Sphere of Attraction of the laſt Plate, the Effect cannot be ſenſible.

Experiment 6.

We remove the Plate R from it's Place, and apply it to the oppoſite Surface of the Plate A B E *. We faſten that Plate in ſuch Manner, that the Edges may not be parallel; but that one may be a little inclin'd with reſpect to the other, as in the fifth Experiment *; and we place them ſo that all the Light may be intercepted at one End. 2752. Pl.86.F.2. * 2731. * 2746.

All Things being now order'd as in the foregoing Experiments, the Phenomena ariſing from the different Breadth of the Space, through which the Light paſſes, are perceiv'd at one View, as in the fifth Experiment; the Figure, in which is repreſented what is here obſerv'd, only differs from the Figure of the ſaid fifth Experiment with reſpect to the Rays diſappearing at one Part, before thoſe are intercepted, which are bent at the oppoſite Part *. Pl.86.F.7. * 2550.

We freely acknowledge, that the Cauſes of the Attraction and Repulſion of Light are conceal'd from us; but the Experiments, explain'd in this Chapter, fully evince, that they do really obtain; more might be added, which does not indeed ſo directly prove Attraction and Repulſion, but ſo manifeſtly flows from them, that, if there was Occaſion, what has been hitherto explain'd, might be confirm'd by other Arguments. 2753.

BOOK V.

PART II. Of the Refraction of Light.

CHAP. IV.

Of the Machines, whereby the Experiments concerning the Refraction of Light are made.

2754. SEVERAL Machines, of which many are ſmall, are made uſe of, in the Experiments, which belong to this ſecond Part of this Book; but as I often uſe the ſame Machines, I thought it beſt, to explain them firſt, that the Series of the Explanation may not be too often interrupted.

A BOX,

In which others are inclos'd.

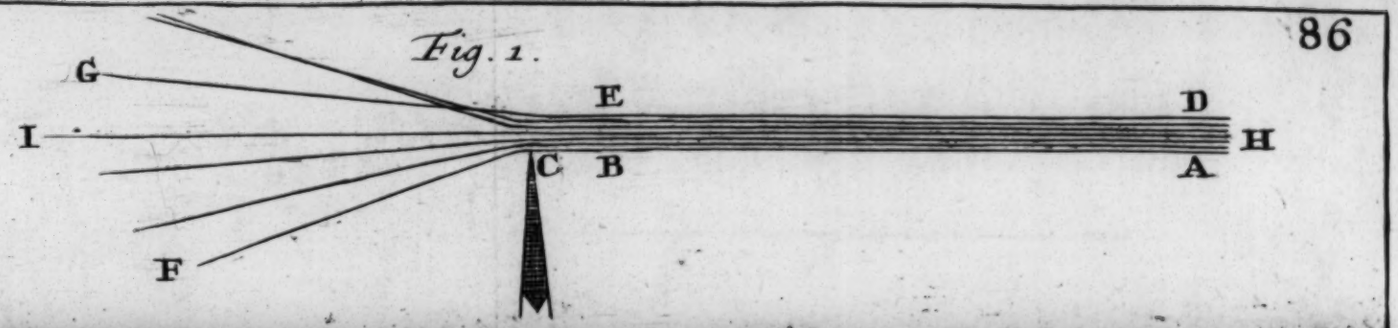
2755. Pl. 87. F. 1. This Box A B is about two Foot and an half long, and five Inches broad and deep. The Sides have Openings, the middle Part being taken away, and the extreme Parts only remaining, as C, D. The middle Part, which is taken away, is ſupplied by two Boards on each Side; as E F, at the fore Part of this Figure; H, G, behind. Theſe Boards are moveable in Grooves as *a b*; F is repreſented in ſuch a Poſition, that if they were all thus, the Box is open'd laterally, as much as it can be.

2756. The Board G is repreſented drawn out of it's Place; if H ſhou'd be drawn out in the ſame Manner, this wou'd meet G; thus alſo E and F may meet.

2757. The Box is open at Top, as alſo at the End B; one End is clos'd, the Hole *d* being left in the Middle, whoſe Diameter is an Inch and a Quarter.

BOXES,

Fig. 1.



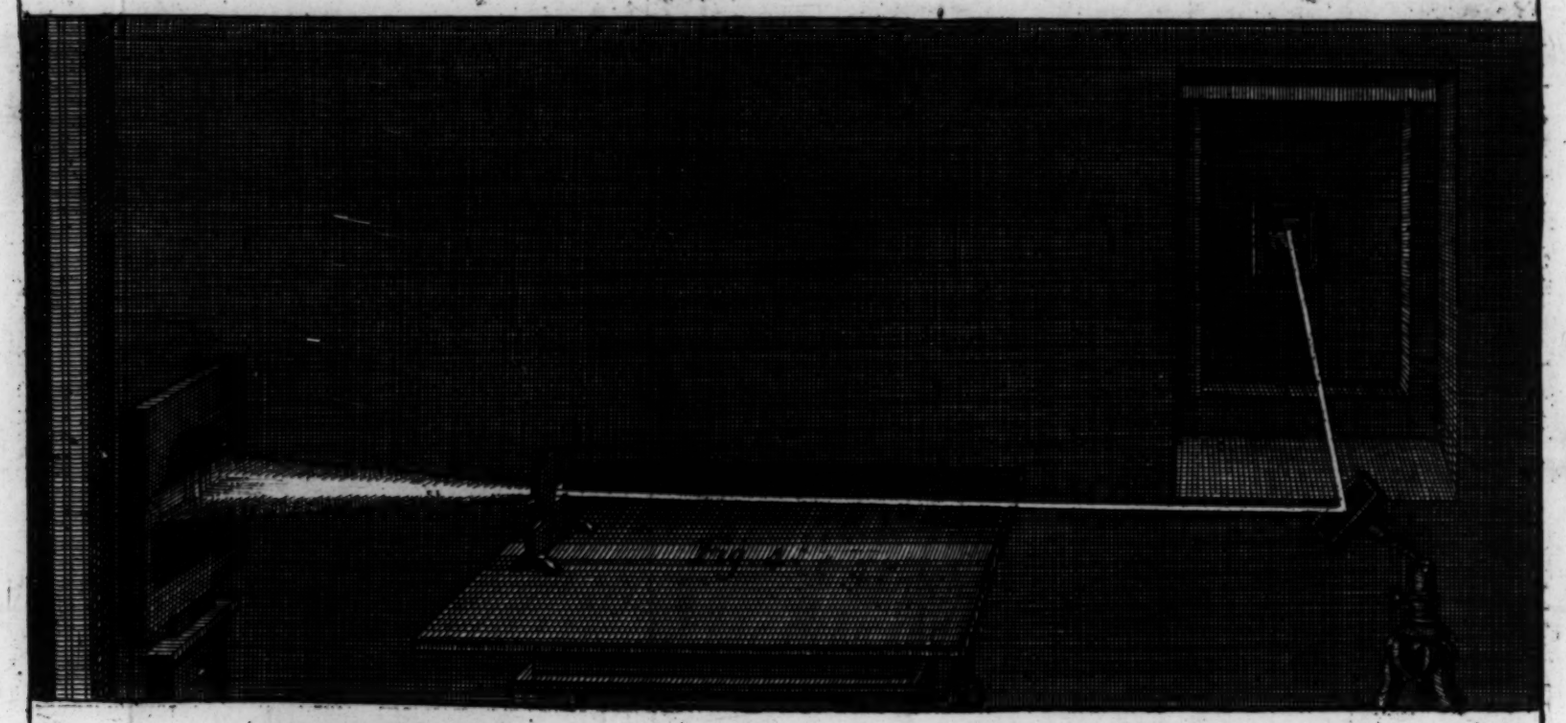


Fig. 5.

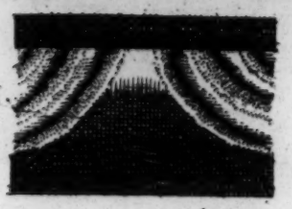




Fig. 2.

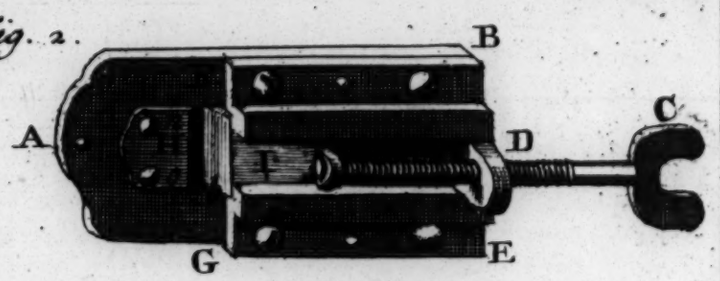


Fig. 6.

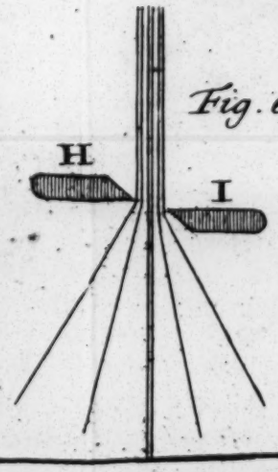


Fig. 7.

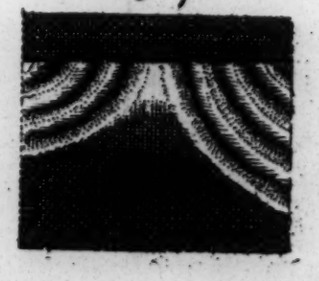
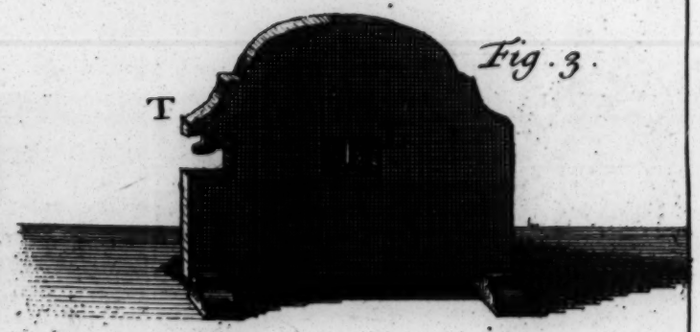


Fig. 3.



J. Mynde sc.

BOXES,
Terminated by Glaſs Planes.

The Box M L I has a wooden Bottom; the End I is alſo clos'd by a wooden Plate; the other three Sides are of Glaſs; but the Pillars L and M are of Wood. The Glaſs Plates are plane and ſmooth, and like thoſe of which looking Glaſſes are made; theſe go into Grooves in the Wood, and are faſten'd, that the Box may hold Water. 2758. Pl.87 F.2.

We have another Box of a ſomewhat different Conſtruction, and I prefer this ſecond Method; I only made mention of the firſt; becauſe the Box is more eaſily made, when the Glaſſes are put into Wood.

The Bottom of the Box P is made of a Braſs Plate R S, whoſe Ends being bent make Feet, whereby the Box is rais'd about one Inch. 2759. Pl.87.F.3.

To this Plate are join'd, and ſtand perpendicularly upon it, the four Braſs Rulers, *a b*, *b c*, *c d*, *d a*, whoſe Ends are join'd at *a*, *b*, *c*, *d*. The four Sides of the Box are of Glaſs, made of Plates, like thoſe above-mention'd. Theſe Plates are applied to a Copper Bottom in ſuch Manner, that they are ſurrounded by the Braſs Rulers, a ſmall Interſtice being left; the Extremities of the Plates come together, but ſo that the ſmaller Plates may be plac'd between the greater ones.

The Glaſs Plates are join'd to the Bottom, and the Rulers, and together, by putting between them a Mixture of Roſin, and white Wax, in a ſmall Quantity. 2760.

BOXES,
That have ſpherical Glaſſes.

The Box P is of Wood, nine or ten Inches long, and three broad in the Inſide. At the Ends of it there are Holes, one of which appears at V; theſe are clos'd with thin Glaſſes, making Portions of Spheres, which are put into the Wood, and faſten'd with Cement. We make uſe of ſuch Glaſſes as are us'd in Watches; thoſe are to be made choice of which are every where of the ſame Thickneſs, and are thin. Theſe Glaſſes are ſo plac'd, that the Convexity of the one may ſtand out beyond the Box, and that of the other may be turn'd towards the Inſide of the Box. It is alſo to be obſerv'd, that the Diameter of the Holes, to which the 2761. Pl.88.F.1.

Glaſſes are applied are equal to an Inch and a Quarter; but that the Diameters of the Glaſſes ought to exceed them half an Inch.

A Section of the Box along the Length is repreſented at *p*, the Glaſſes appear at *v*, *v*.

2762. The Boards T, S, are ſometimes put into the Box; they go acroſs it, and are ſuſtain'd by Means of the Prominences *a*, *b*, and *a*, *b*, and reach almoſt to the Bottom: But that they may keep their vertical Situation, when Water is pour'd into the Box, Lead is put into the Wood at *c d*, *c d*.

2763. In the Board S is faſten'd the Glaſs Q, convex on both Sides, which collects the Sun's Rays at the Diſtance of an Inch.

2764. The Board T is made white; but S muſt be made black, as alſo all the Boxes, and moſt other Inſtruments, which are us'd in Experiments concerning Light.

2765. To the Box P is join'd another A D B, open at A in ſuch Man-
Pl.88.F.2. ner, that either End of the Box P may be put into this End. One End of the Box A B, namely D, is clos'd, and has a Hole in the Middle of it: The Hole is equal to the Holes in the Box P, and anſwers to them in ſuch Manner, that when the Boxes are join'd together, Light may be tranſmitted through the three Holes.

2766. A third ſmaller Box is repreſented at E F; in one of it's long
Pl.88.F.3. Sides there are two Holes V, R, equal and ſimilar to thoſe, which
* 2761. are in the Box P, and clos'd in the ſame Manner with Glaſſes *; the Convexity of the Glaſs at V is on the Outſide, at R it is on the Inſide. In the oppoſite Side G there is put a plane Glaſs Plate, that the Light may come directly to V and R.

The tranſverſe Sections of this Box, along the Centers of the Glaſſes R and V, are repreſented at H and I; the Glaſſes appear at *r*, *v*.

A GLASS CUBE.

2767. The Cube C is made of pure Glaſs; this muſt be nicely work'd,
Pl.87.F.4. ſo that the Figure may be accurately cubical. It's Surfaces muſt be plain, ſmooth, and well poliſh'd. The Sides are equal to two Inches.

In the Experiments this Cube, that it may not be damag'd, is put upon a Piece of black Cloth. It is convenient to make uſe of a Board as T, cover'd with ſuch a Cloth.

BOARDS,

BOARDS,
Through which Light is tranſmitted.

We make uſe of various vertical Boards, for this Purpoſe. In the firſt, whoſe fore Part and hind Part is repreſented, there is a vertical Inciſion *a b*, which is a Quarter of an Inch broad. This is clos'd at the fore Part of the Board, with a Plate of Wood A, which is dove-tail'd, and moves between two Rulers. By this Method the Aperture is terminated, whereſoever you pleaſe, toward this upper Part. 2768. Pl.87.F.5.

Behind the Table there is applied to it a Board B, which is alſo dove-tail'd, and moves between two horizontal Rulers. By Help of this the Aperture is terminated as you pleaſe towards the Bottom. The two Pieces of Wood are made uſe of both together, that the Aperture may be rais'd, depreſs'd, and extended at Pleaſure.

There is a ſecond Board that differs little from the firſt; it's Inciſion is horizontal half an Inch broad, which is diminiſh'd at Pleaſure, by one dove-tail'd Plate only, which moves between Rulers. It is ſufficient to diminiſh the Aperture towards one Way, becauſe the Board itſelf may be mov'd horizontally. 2769. Pl.87.F.6.

We have Occaſion for a third Board T like the other; the Aperture of this is greater, being an Inch and a Quarter broad, and is terminated by a Semicircle both Ways; above this there moves between two Rulers another Board H, which has a Hole in the Middle of A. To the Hole, whoſe Diameter ſhou'd be equal to an Inch and a Quarter, is applied and put into the Wood a convex Glaſs, which collects the Rays of the Sun at the Diſtance of about eight Inches. 2770. Pl.87.F.7.

The Glaſs U anſwers to the Aperture, and may be rais'd, or depreſs'd, the Space of one Inch, without intercepting the Rays tranſmitted through the Glaſs. 2771.

We alſo make uſe of a ſmaller Board T which is furniſh'd with a like Glaſs. A Section of this Board is repreſented at *t* when this is put into one or other of the Boxes mention'd in N. 2755, or 2765, the Light, which is admitted through the Hole at the End of the Box, is tranſmitted through the Glaſs, which is to be ſo ordered, that the Center of it may anſwer to the Center of the Hole. 2772. Pl.88.F.4.

AN HORIZONTAL BOARD.

2773. Oftentimes Inſtruments, and other Things are to be rais'd upon
Pl.88.F.5. a Table to a determined Height which is different according to different Circumſtances. For this Purpoſe we make uſe of a Board T, whoſe Foot is repreſented at P. The Pillars C, C, which paſs through the Holes *a*, *b*, of the Board T, which is then horizontally ſuſtain'd by the round outward Screws E, E, which are placed at the required Height. The Board is faſten'd by applying to it the like outward Screws D, D.

All the Figures of the Machines explain'd in this Chapter, I reduce to a ſixth Part of the true Magnitude.

TABLES,
Whoſe Height may be alter'd.

2774. We make uſe of ſeveral Tables of this Kind; I make uſe of three; the length of one is two Foot and an half, and it's breadth two Foot.

There are two other ſmaller ones fifteen Inches long, and a Foot broad.

The Conſtruction of them is commonly known; to each there is firmly join'd a ſquare wooden Pillar, almoſt two Inches broad and thick, which ſupports the Table. This Pillar is moveable in a Sheath, which is made of four thin Pieces of Wood. This is ſuſtain'd in a vertical Poſition, at the Height of about eight Inches from the ground, three Feet being faſten'd to it's lower End, which ſpread at Bottom.

The Table is rais'd at Pleaſure, by drawing the Pillar out of the Sheath, more or leſs; it is faſten'd by Means of an Iron Screw which paſſes through a Ring of the ſame Metal, which ſurrounds the upper Part of the Sheath. That the Wood may receive no Damage a Copper Plate is put between in ſuch Manner, that the Screw preſſes one End of it, whilſt the other End coheres with the inward Surface of the Sheath, that the Plate may not fall out of
2775. it's Place. By a like Method or any other Method, a Rectangle made of wooden Rulers is rais'd at Pleaſure, and faſten'd, to which is applied a Paper, upon which the Light falls, in many Experiments. Such a Rectangle is of uſe in the Experiments of the foregoing Chapter.

Fig. 1.

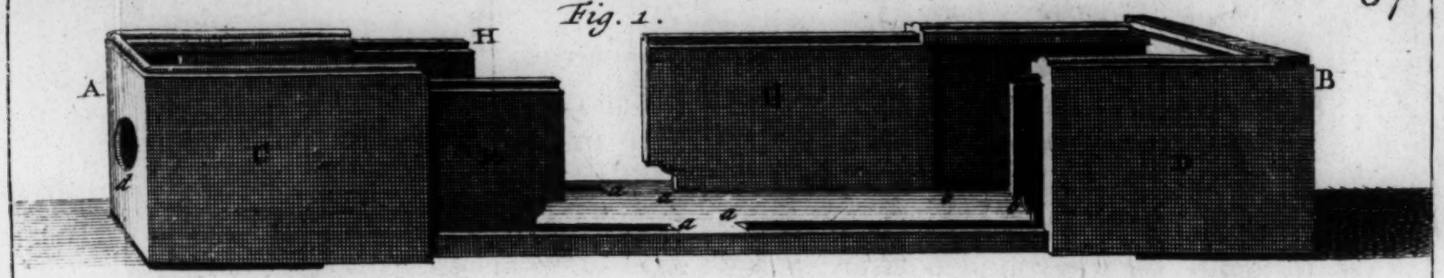


Fig. 2.



Fig. 4.

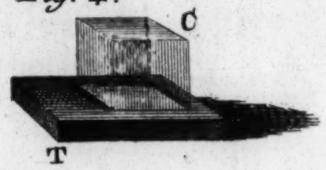


Fig. 3.

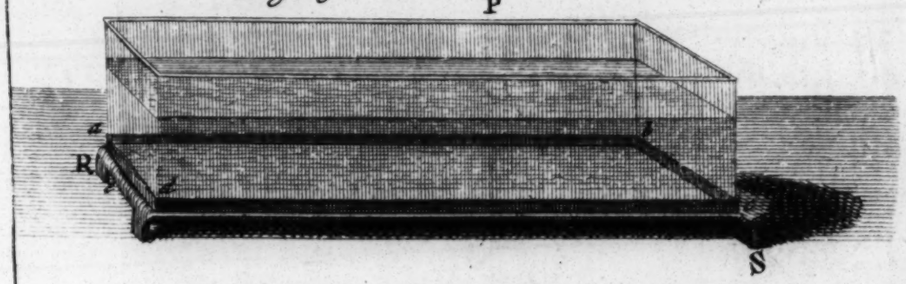


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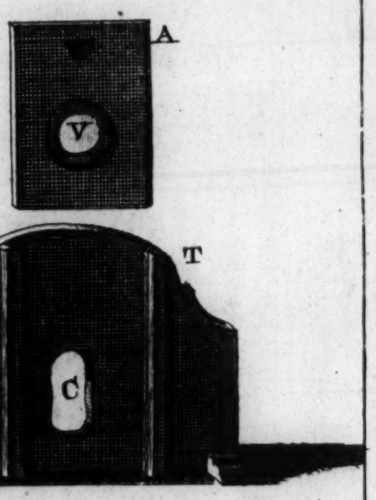
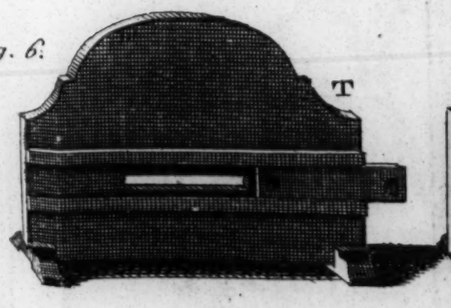


Fig. 6.



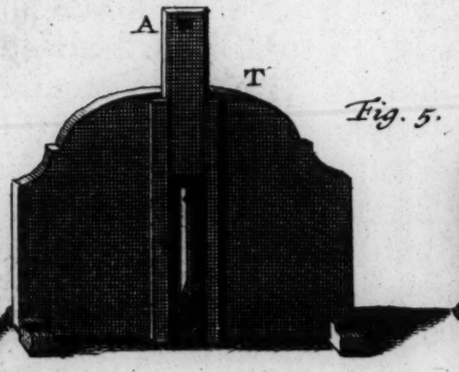
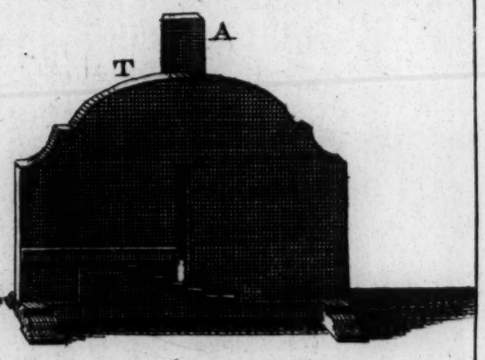


Fig. 5.



J. Mynde sc.

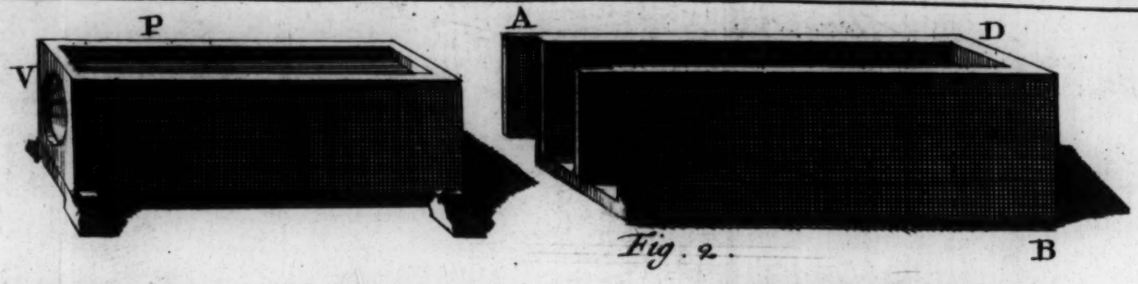


Fig. 2.



Fig. 1.

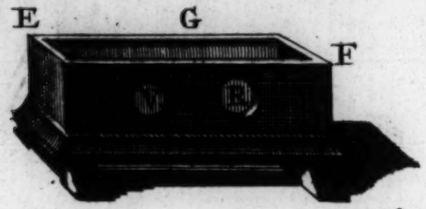


Fig. 3.

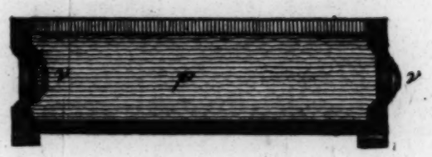
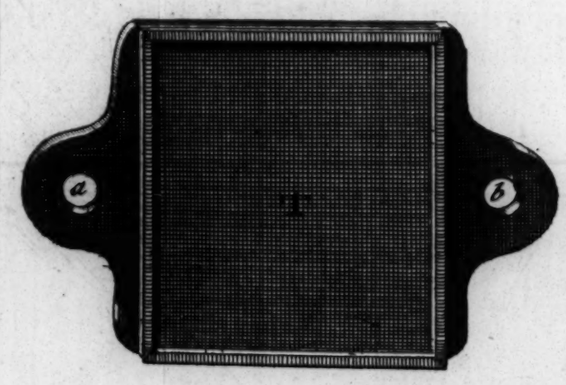






Fig. 4.



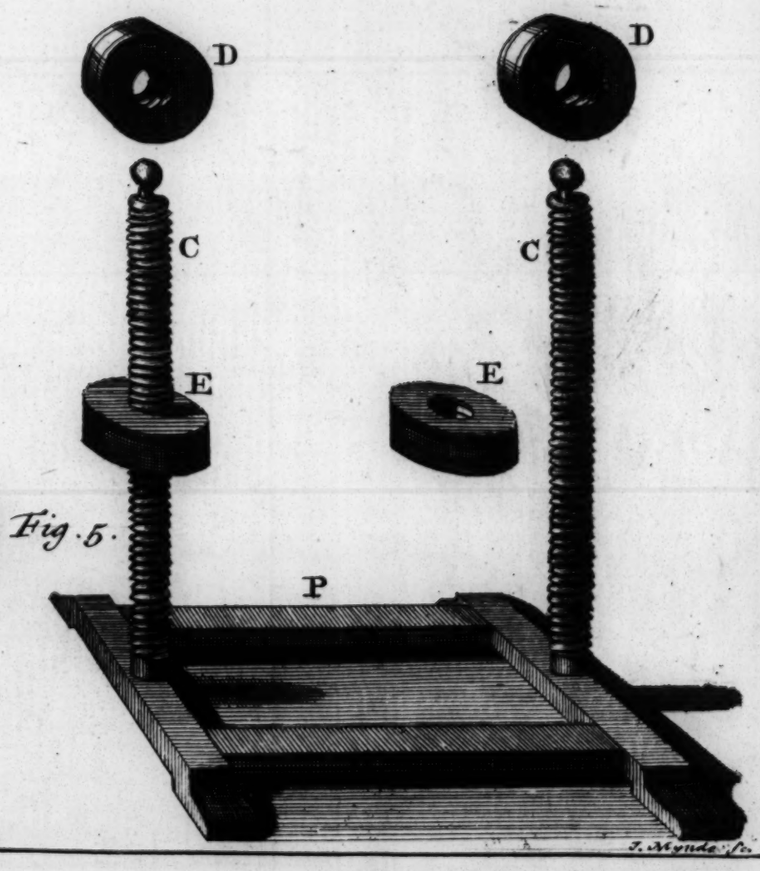


Fig. 5.

J. Meyndt sc.

CHAP. V.

Of the Refraction of Light, and it's Laws.

DEFINITION 1.

EVERY thing that gives a Paſſage to Light is call'd a Medium. 2776.

All pellucid Bodies, * a Vacuum, are Mediums. * 2614.

Whilſt a Ray of Light goes out of one Medium into another, it often turns out of it's Way.

DEFINITION 2.

This Inflection is call'd Refraction.

In order to produce Refraction, the Medium muſt be of different Denſities, and the Ray make an oblique Angle with the Surface which ſeparates the Mediums. 2777. 2778.

Refraction ariſes from this, that the Rays are more attracted by a denſe than by a rare Medium; from which Attraction, all that we have proved in the foregoing Chapter, relating to Refraction, is deduc'd. 2779.

Let EF be the Separation of the Mediums; let the Medium be denſer, and rarer towards Z. All the Particles of Matter attract Light *. Let the Diſtance, at which Particles exert their Action, be that contained between theLines EF, and GH. Therefore the *Light*, which comes between theſe Lines, *will be attracted by the denſer Medium* X; and indeed *perpendicularly to the Surface, which ſeparates the Mediums*; for the oblique Actions on every Side are ſimilar and equal, and jointly draw perpendicularly. Pl.89.F.1. * 2723. 2780.

At the Diſtance of the Line GH, the extreme Particles of the Medium X do only act upon the Light; at a leſs Diſtance, both theſe and other Particles act ſo as to increaſe the attractive Force, when the Diſtance is diminiſh'd, as has been obſerv'd before *. In the denſer Medium X, let the Line IL be at the ſame Diſtance from EF as GH is in the Medium Z. Let the Light enter into the Medium X, and it will every Way be attracted by the Particles of the Medium, whoſe Diſtances from the Light are leſs than the Diſtance between EF and GH; for at that Diſtance the Light is ſuppoſed to be attracted by the Particles of the Medium X. 2781. * 2725.

As

As long as the Light is between the Lines E F and I G, the attractive Force is the ſtrongeſt towards I L; becauſe there are more Particles that attract that Way: But as the Number of Particles, acting the contrary Way, does increaſe, that is, as the Diſtance from E F increaſes, the Force towards I L diminiſhes, till the Light be equally attracted every Way in that Line I L, which alſo is every where ſo in the Medium X beyond I L.

2782. Suppoſe a Ray of Light A *a* to fall obliquely upon the Surface dividing the Mediums, or rather on the Surface G H, where the Action begins, by which the Light is driven towards the Medium X; when the Ray comes to *a*, it is turned out of the right Line by the Force, wherewith it is driven towards it in a Direction perpendicular to it's Surface. And indeed the Ray of Light is bent out of the right Line in every Point, ſo long as it is between the Lines G H and I L, between which the ſaid Attraction acts; and ſo the Ray deſcribes the Curve *a b* between thoſe Lines, after the ſame
* 540. Way as has been ſaid Projectiles do * the Action, bending the Ray, ceaſes beyond the Line I L; therefore it goes on afterwards in a right Line *b* B, being the Tangent to the Curve in the Point *b*.

The Diſtance between the Lines G H and I L is but ſmall:
2783. Therefore *in Refraction* we take no Notice of the bent Part of *the Ray, which is conſider'd as made up of two right Lines* A C, C B, *meeting* in C, *viz. In the Surface ſeparating the Mediums.*

Through C draw N C M perpendicular to the Surface E F.

Definition 3.

2784. *The Part A C of the ſaid Ray, is call'd the incident Ray.*

* 1161. The Angle A C N is the Angle of Incidence *.

Definition 4.

2785. *The Part C B of the Ray, is call'd the refracted Ray.*

Definition 5.

2786. *The Angle B C M is call'd the Angle of Refraction.*

2787. In this Caſe *when Light goes out of a rarer into a denſer Medium, the Angle of Refraction is leſs than the Angle of Incidence*; for theſe Angles wou'd be equal, if the Ray A C ſhould have continued on it's ſtrait Way, along the Line C D. But the Ray C B comes nearer to the perpendicular C M; and *therefore the Refraction is ſaid to be made towards the perpendicular.*

On

On the contrary, *if the Ray goes out of a denſer Medium into a rarer, it will recede from the Perpendicular*; becauſe the denſer Medium attracts the Ray after the ſame Manner, whether it goes out of a rarer into a denſer, or out of a denſer into a rarer Medium. Therefore if B C be the Ray of Incidence, C A will be the refracted Ray, that is, *let the Ray come from either Side, and it will move in the ſame Line.* 2788. 2789.

Therefore *if there be two Rays, and one comes out of a denſer into a rarer Medium, and the other out of a rarer into a denſer; and the Angle of Refraction of the one be equal to the Angle of Incidence of the other, the two Angles of Incidence and Refraction remaining will be equal to each other.* 2790.

Let X be a Medium terminated by the Parallel Surfaces E F, H L, by which Z is ſeparated from the ſame Medium on both Sides; we ſuppoſe X to be denſer, it is no Matter if it be rarer. The Light enters along A C, is refracted along C B, and goes out along B G, N C M, P B O, being drawn perpendicular through C and B, the Angle M C B, C B O are equal * therefore, by Reaſon of Attraction on both Sides acting in the ſame Manner, the Angles A C N, P B G, are alſo equal, but the Angle M C B is the Angle of Refraction, and the Angle C B O is the Angle of Incidence in the ſecond Refraction; therefore the two other are equal. 2791. Pl.89.F.2. * 29.El.1.

From whence it follows, that *the Direction of the Ray is not changed, if it moves through a Medium terminated by two parallel Surfaces:* For as much as it is turned at it's Entrance towards one Side, ſo much exactly is it turned the other Way as it goes out of the ſaid Medium. It is manifeſt that the Rays A C, B G, which are equally inclin'd to the Parallels M N, O P, are alſo parallel. 2792.

If a Ray falls perpendicularly upon the Surface ſeparating two Mediums, it will not be turned out of a right Line by the Attraction of the denſer Medium; becauſe in that Caſe it acts in the Direction of the Ray. 2793.

Experiment 1.

We faſten the ſmall Side-Board * to the Box, in which the Helioſtate is inclos'd, in ſuch Manner that it may not quite cloſe the Aperture, to which it is applied †; but it wants three Inches towards the Bottom, where there is left open a ſquare Hole, through which Light is to be reflected horizontally *. But in order to exclude the extraneous Light, we apply a ſquare wooden Tube, about a Foot long, and the Light is directed through the Tube. 2794. Pl.89.F.3. * 2703. † 2707. * 2698.

This Tube is laid upon a ſmall Table, whoſe Height may be
* 2774. alter'd *.

2795. If the following Experiments are to be made without the Helioſtate, the Light is let into a Place which is otherwiſe clos'd through a ſquare Hole of three Inches in the Window, and re-
* 2735. flected horizontally *.

2796. We make uſe of the long Box C A deſcribed above *; which
* 2755. we ſo diſpoſe, that the Light may enter in through the open End, and follow the length of the Box. The Light in it's Ingreſs is in-
* 2768. tercepted by the Board T *, and only let through a Slit in it.

When the Box is open towards the Sides, we put through it the
* 2758. Box P, which is terminated by Glaſs Planes * in a tranſverſe Poſi-
2759. tion. Towards this are mov'd the ſide moveable Boards of the firſt, which is thus clos'd as much as poſſible.

Water is pour'd into the Box P to half it's Height, ſo that a Ray of Light paſſes partly through the Water, and partly above it. The Aperture of the Slit in the Board T muſt be ſo terminated, that the Light may not fall upon the Bottom of the Box P, nor paſs
* 2768. above the Box *.

2797. Theſe Things being thus order'd, and the Box being turned in ſuch a Manner, that a Ray may fall upon *a b* perpendicular to it's Surface; the Light will paſs through the Water in a right Line, as alſo through the upper Part of the Box, and neither in it's coming in, nor in it's going out, will it be turned out of it's Way, as was ſaid in N. 2793.

Experiment 2.

2798. The ſame Things being ſuppos'd, let a Ray fall obliquely upon the Surface of the Box; the upper Part of the Ray will continue it's Motion through *c* to *d* in a right Line; but the lower Part in the Water, will be bent towards *e*, approaching towards the Perpendicular: Which confirms Number 2787.

Experiment 3.

2799. Things remaining as in the foregoing Experiments; the Ray which at *e*, paſſes out of the Water into the Air along *f e*, is turn'd out of it's Way in receding from the Perpendicular; and indeed in ſuch Manner, as to follow the ſame Direction with the Ray falling upon the Water at *e*; for *a c d*, *e f* are parallel. Which confirms Numbers 2788, 2789, 2792.

EXPERIMENT 4.

Theſe Experiments anſwer in the ſame Manner, if inſtead of Water we make uſe of Glaſs. Then we uſe another Box A D *; the open End of which is clos'd by the Board T †, as in the foregoing Experiments. Part of the Light paſſes through the Glaſs Cube C *, and Part paſſes above it; if we make the three laſt Experiments this Way, the Event will be the ſame; but the Refraction is greater in the Glaſs than in the Water. 2800. Pl.89.F.4. * 2765. † 2768. * 2767.

To make the Way of the Light along the Air ſenſible to us, we put Flower into a Bag made of fine Linen, and tie up the Mouth of it. This is ſhaken, that the Flower may be diſpers'd in that Place, along which the Light paſſes; which in paſſing along illuminates ſtrongly the ſmall Particles of the Flower, which come in it's Way. 2801.

In what has been ſaid hitherto, we have only conſider'd the Attraction of the more denſe Medium, becauſe this prevails; but the Action of the rarer Medium is not to be overlook'd, becauſe this diminiſhes the Action of the denſer Medium, which will be ſo much the leſs upon the Light, as the Mediums differ leſs from one another in Denſity. Therefore *there is no Refraction, when the Denſities of the Mediums are equal; and it is the greater, the more theſe Denſities differ from one another.* 2802. 2803.

The Laws of Refraction are deduc'd from the Acceleration, which the Attraction generates. 2804.

The Attraction obtains between the Planes, repreſented by the Lines G H and I L, and no farther *. 2805. Pl.89.F.1. * 2780.

DEFINITION 7.

For this Reaſon *we call the Space, terminated by theſe Planes, the Space of Attraction.* 2806.

In the following Scholium we demonſtrate that, although the Action of a Body upon Light be directed perpendicular to the Surface, the Acceleration of Light, in it's Motion from a more rare into a denſer Medium, or the Retardation in a contrary Motion, is the ſame, in what Direction ſoever the Light be carried; the Acceleration, or Retardation, is indeed leſs in a more oblique Motion, but it laſts longer, which makes a Compenſation. 2807.

Therefore, *there is a conſtant Ratio between the Velocities of Light in two given Mediums.* This may indeed be demonſtrated, by applying here, what was demonſtrated concerning the Deſcent of 2808.

heavy Bodies in the firſt Book; but it is illuſtrated more in the ſaid
2809. Scholium, in which we alſo demonſtrate, that *in every Inclination of the incident Ray there is a conſtant, and immutable Ratio between*
2810. *the Sines of the Angles of Incidence and Refraction*; *and* that *theſe Sines are inverſly, as the Celerities in thoſe Mediums.*

2811. If the Mediums be Air and Water, the ſaid Sines are as 4 to 3, and the Celerities of Light in the Air are to it's Celerity in Water, as 3 to 4. But if, the Air remaining, the other Medium be Glaſs, the Sines are as 17 to 11; one Experiment will ſuffice to ſhew this with reſpect to all the Mediums.

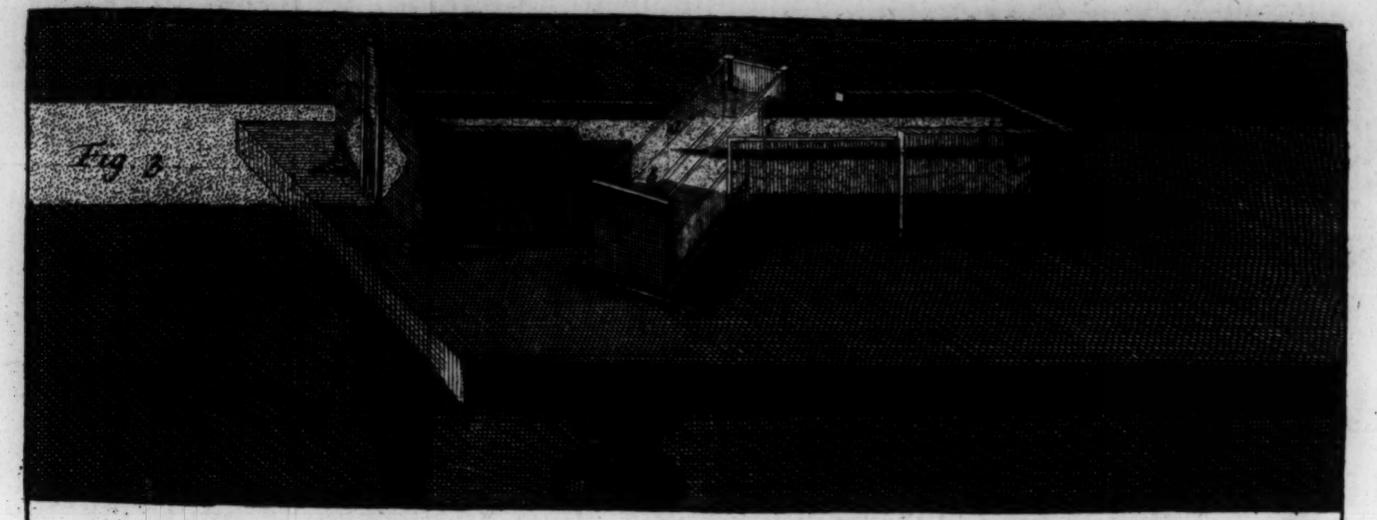
2812. The Angle DCM, is equal to the Angle of Incidence ACN *,
* 15. El. 1. and the Quadrant of the Circle FDM being deſcrib'd, the Sine of that Angle is D*o*; the Sine of the Angle of Refraction BCM is TR; the Ratio between theſe is conſtant. VDB being drawn parallel to CM, BS, which, with D*o* and RT, we ſuppoſe per-
* 34. El. 1. pendicular to CM, is equal to D*o* *; and the ſaid conſtant Ratio will take Place between BS and RT; as alſo, by Reaſon of the ſimi-
* 4. El. 6. lar Triangles BSC, TRC, between BC, and TC *, or DC; for theſe are Rays of the ſame Circle; but if we ſuppoſe the Circle deſcrib'd with the Center C, through the Point V, the Lines BC,
2813. DC, are *the Co-ſecants of the Angles of Refraction and Incidence*; which therefore *are inverſly as the Sines of the ſame Angles*; which is the known Property of Co-ſecants.

It is confirm'd by the following Experiment, that there is a conſtant Ratio between the ſaid Co-ſecants.

Experiment 5.

2814. We make uſe of the ſame Box MI *, that was us'd in the firſt
Pl. 90. F. 1. Experiment; this, as in that Experiment, is half fill'd with Wa-
* 2758. 2759. ter; the Light is tranſmitted through the ſame Board, as was in the ſaid Experiment. The Box is ſo diſpos'd, that the Light may enter into it obliquely through the Glaſs Plate at the End of it; the Ray paſſes through this Plate in the Line *a b*, the upper Part moves above the Water in a right Line along *a c*, and runs againſt the Side of the Box at *c*; the lower Part is refracted along *b e*, and ſtrikes againſt the ſame Side at *e*. Howſoever the Incidence of the Rays be alter'd, *a c* is always to *b e*, as 3 to 4, inverſly as the Sines
* 2811. of the Angles of Incidence and Refraction from Air into Water *. But theſe Lines *a c*, *b e*, are Co-ſecants of the ſame Angles.

SCHO-



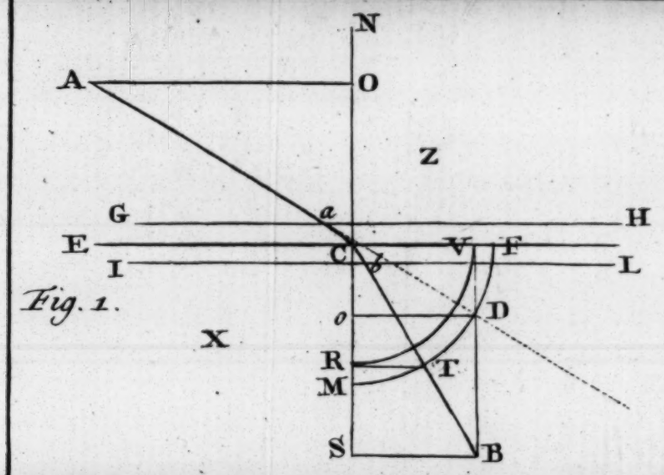


Fig. 1.

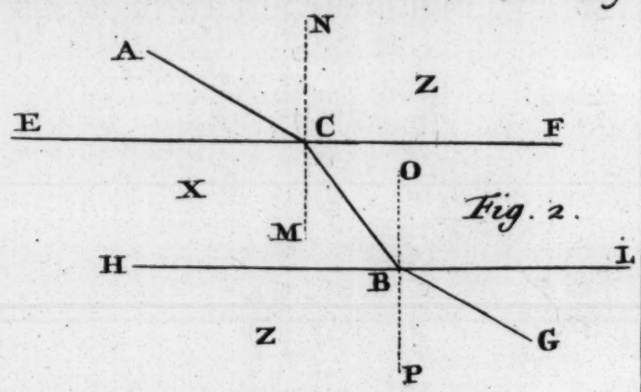
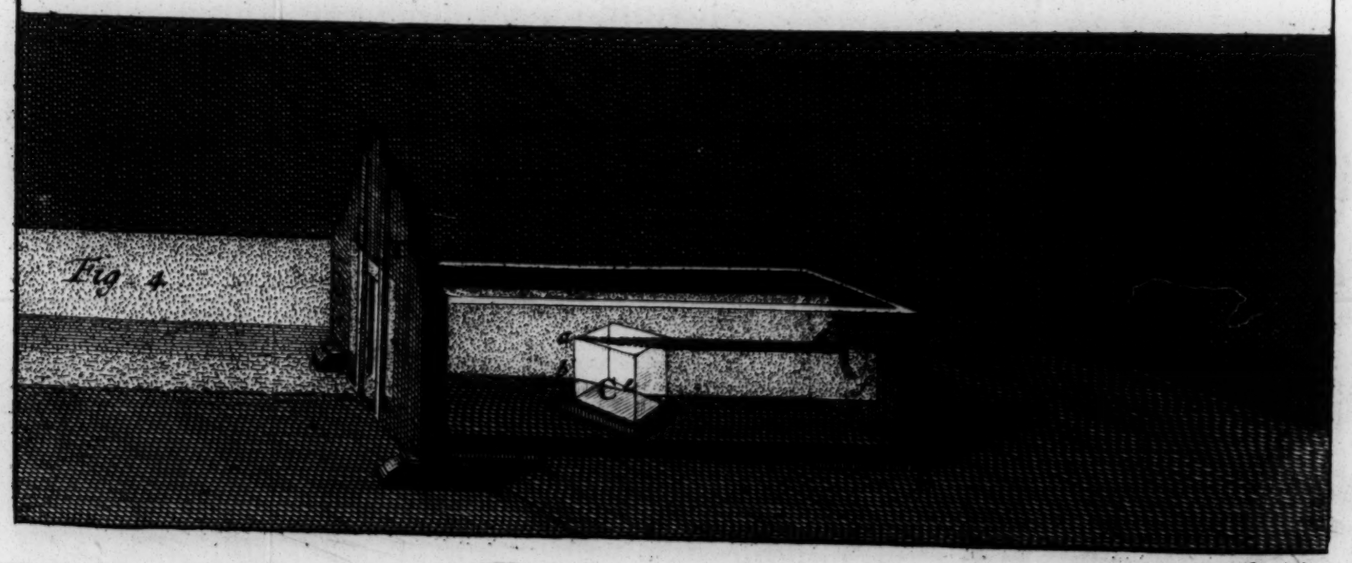


Fig. 2.



J. Myndse.

SCHOLIUM.

Demonſtrations of the Laws of Refraction.

WE have ſeen that the Attraction of Light only takes Place in it's Paſſage along the Space of Attraction * ; therefore we muſt examine, what happens to Light in that Paſſage. 2815. * 2805.

The Direction of the Action of the Medium upon the Light is perpendicular to the Surface dividing the Mediums * ; and therefore, in this Caſe, to the Surface IL ; *and it is unequal at different Diſtances from this Surface* * ; *but at equal Diſtances it is equal* ; becauſe both Mediums are ſuppos'd homogeneous, and every where ſimilar. 2816. Pl. 89. F. 1. * 2780. * 2781.

The Motion of the Ray AC may be reſolv'd into two other Motions along AO and OC *, the firſt of which is parallel to the Surface EF, the ſecond is perpendicular to the ſame Surface ; the Celerities of whoſe Motions will be reſpectively proportional to theſe Lines AO and OC, whilſt AC repreſents the Celerity of the Ray itſelf *. 2817. * 319. * 319.

The Motion along the Direction AO is not alter'd by the Attraction, perpendicular to the Surface IL, only the Motion along OC is accelerated. 2818.

The Line AC being kept, namely the Celerity of the Ray itſelf, it's Inclination may be alter'd, whereby the Celerity along the Direction OC is alſo chang'd ; which Celerity is nothing, if the Angle A*a*G be very ſmall. In which Caſe, if after the Ingreſs of the Light into the denſer Medium, it's Motion be reſolv'd into two in ſuch Manner, that the Direction of the one be perpendicular to the Surface IL, it's whole Celerity will be to be attributed to the Attraction often mention'd. For in the Ingreſs into the Space of Attraction the Motion along this Direction is generated, which in the Paſſage along this Space, in which there is every where a new Action, acts upon the Light, in the ſame Direction, is continually accelerated. This Acceleration obtains in every Paſſage of the Light along the Space of Attraction, but is different according to the different Celerity, with which the Light comes perpendicularly to the Surface ſeparating the Mediums. 2819.

If the Attraction were equable through the whole Breadth of the Space of Attraction, what relates to the Acceleration mention'd, as we have demonſtrated concerning the Acceleration of heavy Bodies *, might be determin'd by Means of the Right-angled Triangle PQR, in which the Lines, parallel to the Baſe, repreſent the Celerities, whilſt the Portions of the Area of the Triangle repreſent the Spaces run through. But we here ſpeak always of the ſame Space run through, namely the Breadth of the Space of Attraction, becauſe we only conſider the Motion perpendicular to the Surface ſeparating the Mediums ; therefore this Space run through is always repreſented by equal Portions of the Area of the Triangle PQR. Let this Portion be P*dc*, when the Light enters the Space of Attraction, in the ſaid perpendicular Direction, with the Velocity *o* ; that is, when the 2820. Pl. 90. F. 2. * 373.

the incident Ray makes the ſmalleſt Angle with the Surface ſeparating the Mediums; *de* in this Caſe will repreſent the Celerity acquir'd by the Attraction, and with which the Light goes out of the Space of Attraction.

2821. If the Light enters the Space of Atttraction perpendicularly, with the Celerity repreſented by *f g*, it will go out of that Space with the Celerity *hi*, the Arches P*dc* and *fgih* being put equal to one another, as appears from what has been ſaid. The Triangles P*dc*, P*fg*, P*hi* are ſimilar; and therefore their Archs are in a duplicate Ratio to one another; that is, as the Squares of the homologous Sides *dc*, *fg*, *hi* *; but the Sum of the Areas P*dc*, P*fg* is equal to the Area P*hi*, (by Reaſon of the equal Areas P*dc* and *fgih*;) therefore alſo the Sum of the Squares of the Lines *dc* and *fg* is equal to the Square of the Line *hi*; whence it follows that the Triangle, form'd by theſe three Lines, is rectangular, and that it's Hypotenuſe is *hi* *. Therefore

* 19. El. 6.

* 48. El. 1.

2822. *In a Right-angled Triangle, one of whoſe Sides is the Celerity, with which the Light enters into the Space of Attraction perpendicularly, and the other Side the Celerity acquir'd in running through this Space, when the Light enters into it with the Celerity* o, *the Hypotenuſe of the Triangle repreſents the Celerity, with which the Light goes out of the Space of Attraction perpendicularly at the oppoſite Part.* Which obtains univerſally, howſoever the Attraction be alter'd in the Space of Attraction according to the different Diſtance from the Planes, by which this Space is terminated. To prove which,

2823. Let us ſuppoſe the Space of Attraction to be divided into two Parts either equal, or unequal, by a Plane parallel to the Surfaces, by which it is terminated. Let us further ſuppoſe that there is a different Attraction in theſe Parts, but that it is not different in the ſame Part. Theſe Parts are to be conſider'd as two different Spaces of Attraction. Let A be the Celerity, which the Light acquires in running through the firſt Part of the Space, when it enters into that Space with the Celerity *o*; let B be the Celerity, acquir'd in running through the ſecond Part of that Space, when the Light enters this Part in like Manner with the Celerity *o*. It muſt be obſerv'd that in this Demonſtration we every where conſider the Motion perpendicular to the Surface, ſeparating the Mediums.

Pl. 90. F. 3.

Let the Light enter the firſt Part of the ſaid Space with the Celerity *o*; it will come to the ſecond Part with the Celerity A; if therefore the Right-angled Triangle ECD be form'd with the Sides A and B, the Hypotenuſe ED will repreſent the Celerity, with which the Light will go out of the Space of Attraction *.

* 2822.

Plate 90. Fig. 3, 4.

If the Light enters into the Space of Attraction with the Celerity FG, let the Right-angled Triangle HFG be form'd with the Sides FG and A; the Hypotenuſe HG will be the Celerity, with which the Light goes out of the firſt Part of the Space of Attraction *, and enters into the ſecond; but by forming the Right-angled Triangle HGI, whoſe perpendicular is equal to the Line B, there is given the Hypotenuſe IG, repreſenting the Celerity, with which the Light goes out of, and continues it's Motion after it has run through the whole Space of Attraction *.

* 2822.

* 2822.

But

But we muſt demonſtrate, that the Celerity I G is alſo the Hypotenuſe of the Right-angled Triangle N M L, whoſe Side M L is equal to F G, the Celerity with which the Light enters into the Space of Attraction, and whoſe other Side, L N, is equal to the Line E D, the Celerity, which the Light acquires, in running through the whole Breadth of the Space of Refraction, when it has enter'd into it with the Celerity *o*; which being demonſtrated, it will appear that the Propoſition of Number 2822, obtains in this Caſe alſo, in which two different Forces of Attraction act. 2824.

But it plainly appears from the Conſideration of Right-angled Triangles that the Lines I G and N M are equal. The Square of the Line N M is equal to the Squares of the Lines N L and L M, or F G: N L, is equal to the Line E D, whoſe Square is equal to the Squares of the Lines E C and C D, or the Lines A and B, which are equal to the Lines F H and H I: Therefore the Square of the Hypotenuſe N M is equal to the three Squares of the Lines F G, F H, and H I. To the ſame three Squares the Square of the Line G I is equal; for this is equal to the Squares of the Lines H I and H G; which laſt is equal to the Squares of the Lines H F and F G.

If the Space of Refraction be divided into ever ſo many Spaces, by Planes parallel to the Surfaces, by which this Space is terminated, and different Forces of Attraction obtain in different Parts, the ſame Demonſtration *will take Place*; and the Number of Diviſions may be increas'd at Pleaſure *in infinitum*; which is the Caſe *in the Refraction*, which Light undergoes in paſſing out of any Medium whatever into another of different Denſity *; to which therefore *the Rule of Number* 2822, may be applied. 2825. * 2816.

Let Z be the more rare Medium, X the denſer, and let them be ſeparated by the Plane E F; let there be a Ray of Light A C, falling upon the Surface E F obliquely; let A C repreſent the Celerity of the Light in the Medium Z, and let this Line A C be conſtant; that is, let it remain, whatſoever the Inclination of the Ray ſhall be. Deſcribe a Circle with the Center C, and Semidiameter C A; let N C M be perpendicular to E F; draw from A the Perpendiculars A O to N C, and A Q to E F. 2826. Pl. 90. F. 5.

Let the Motion along A C be conceiv'd to be reſolv'd into two others, one along A O, the other along A Q or O C *; the Line O C will repreſent the Celerity of the Ray perpendicular to the Surface E F, which Celerity alone is increas'd from the Attraction of the Medium *. * 319. * 2818.

Let C P be the Celerity, which the Light acquires in paſſing through the Space of Attraction of the Medium *x* perpendicularly, *o* being ſuppos'd the Celerity of the Light in it's Ingreſs; the Hypotenuſe O P of the Right-angled Triangle P C O will be the Celerity of the Ray A C in the Medium X, in the Direction perpendicular to the Surface E F *; the Celerity of the Light in the Direction A O, or Q C, parallel to the Surface E F is not alter'd *. Therefore let C V be equal to A O, or Q C, and V B perpendicular to E F, equal to the Hypotenuſe P O, and draw C B; the Motion along C B will be the Motion compounded of the two, and this Line by it's Poſition determines the Direction, and by it's Length *the* * 2825. * 2818. 2827.

* 318. *Celerity, of the Light in the Medium* X * ; which Celerity *is not alter'd by the different Inclination of the Ray* AC. For the Square of the Line CB is equal to the Square of the Line BV, or PO, and the Square of the Line CV, or AO ; but the Square of the Line PO is equal to the Squares of the Lines PC and CO ; therefore the Square of the Line CB is equal to the three Squares of the Lines PC, CO, and AO ; which two laſt if they be join'd, we ſhall have the Square of the Semidiameter AC, or CN ; that is, CB is equal to PN, whoſe Square is alſo equal to the Squares of the Lines PC and CN, and which is not alter'd when the Inclination of the Ray AC is chang'd.

The Line CB cuts at T the Circle deſcrib'd with the Semidiameter CA ; draw from the Points B and T, BS and TR perpendicular to CM : By Reaſon of the ſimilar Triangles CBS, CTR, BC will be to TC, or CA, as BS to TR ; which Lines therefore, by Reaſon of BC and CA being conſtant, will always be in the ſame Ratio, whatſoever the Angle of Incidence be. TR is the Sine of the Angle of Refraction TCR ; and BS, equal to CV, equal to AO, is the Sine of the Angle of Incidence ACO ; between which Sines therefore there is a conſtant Ratio, as was ſaid in N. 2809.

2828. We have hithertho conſider'd a Ray paſſing out of a rarer Medium into a denſer ; but the ſame conſtant Proportion of the Sines obtains in a contrary Motion of the Rays ; the Angles ACN, MCB are not alter'd,

* 2789. whatſoever the incident Ray be, whether AC or BC *. In this Caſe if BC be the Celerity of the incident Ray, CA will be the Celerity of the refracted Ray ; for the Motion of the Ray paſſing out of X into Z is retarded in the ſame Manner, from the Attraction towards the Medium X, as it is accelerated in the contrary Motion.

CHAP. VI.

Of the different Action of different Bodies upon Light.

2829. WE have ſeen that all the Particles of Bodies act upon Light ; in the laſt Chapter we reaſon'd as if they all acted equally ; when this obtains, what was ſaid, is always true, that the denſer Medium attracts Light more ſtrongly than the rarer ; and that therefore the Refraction from the rarer Medium into the denſer is

* 2787. towards the Perpendicular * ; in this Caſe alſo the refracting Force follows the Ratio of the Denſity of the Body. We conſider'd the Thing in this Manner, becauſe we thought it beſt to bring it to the greateſt Simplicity, at the firſt Examination.

2830. This indeed is the Caſe in many Bodies ; in Air, Glaſs of An-

2831. timony, the Selenites, common Glaſs, Mountain Cryſtal, and *in*

many other *Bodies, the refracting Force is ſenſibly as the Denſity; but this is not a* general Rule. 2832.

But the Particles of ſeveral different Bodies act differently upon Light; but they may be reduc'd to different Claſſes, in each of which the Rule mention'd * takes Place. 2833. * 2831.

Such a Claſs has been juſt mention'd *. *Unctuous Bodies make another Claſs*, to which we reduce Camphire, Oil of Olives, Linſeed Oil, Spirit of Turpentine, and ſuch like Bodies. 2834. * 2830.

In all theſe the refracting Force of all the Particles is ſenſibly the ſame, and this very much exceeds the Force which obtains in the foregoing Claſs *. 2835. * 2830.

Many Bodies conſiſt of Particles whoſe Action upon Light is intermediate, and which may be brought to intermediate Claſſes when the Refractions of many Bodies ſhall be determin'd. 2836.

Sir *Iſaac Newton* determin'd the Force, with which Particles act, in twenty two Bodies; and the Table, which he has given relating to them in his Opticks, might be extended to many other Bodies, if for all, one Experiment only concerning Refraction be made. But how the Force of the Particles is collected from the Experiments concerning Refraction, the Denſity being given, will be explain'd in the next *S*cholium. 2837.

Hence it follows that all, that was ſaid concerning Refraction in the laſt Chapter, may be applied to all the Claſſes; but this does not always obtain in the Paſſage of Light from a Body of one Claſs into a Body of another, as appears from the following Experiments. But how the Propoſitions are to be alter'd to make them univerſal, I ſhall now ſay. 2838.

All the Reaſoning, laid down in the laſt Chapter, is founded upon the Attraction of Light by Bodies; and we have demonſtrated that there is a Refraction, when the Attraction is greater on one Side, than on the other; whereſoever this obtains, the Demonſtrations take Place; but this obtains, as often as one of two Contingent Mediums acts more ſtrongly upon the Light than the other. Therefore *the Demonſtrations will be general, if, what was ſaid of a denſer Medium, be applied in general to the Mediums whoſe Action upon Light is greater.* 2839. 2840.

But *this Action is as the Force, with which all the Particles act, and* as the Number of Particles acting together, that is, as the Number of Particles, contain'd in a certain Space; which Number is *as the Denſity of the Body*, 2841.

For except we correct the Propoſitions thus, that were deliver'd in the laſt Chapter, which, as they are commonly found in Optick Writers, we have alſo given, many of them will be falſe.

2842. For *Light may undergo a Refraction*, in it's Paſſage out of one Medium into another, *although the Mediums do not differ in Denſity*, which is contrary to Number 2778.

2843. In the Paſſage of Light, out of Alum into Vitriol, the Refraction is towards the Perpendicular, the Sine of Incidence is to the Sine of Refraction, as 26 to 25; yet the Denſities are equal; but the Forces, with which the Particles of theſe Bodies act upon Light, are to one another as 20 to 23.

2844. *Light may paſs* out of one Medium into another, in any Direction whatever, *without any Refraction, though the Mediums differ in Denſity*; which does not agree with N. 2779.

Experiment 1.

2845. We pour Oil of Olives into a Glaſs; if this be cylindrical or conical, the Figures of the Objects, ſeen through the Oil, appear alter'd, but they are diſtinct. Moreover we make uſe of a Piece of Borax, very tranſparent, but whoſe Figure is ſo irregular, and it's Surface ſo unequal, that the Objects will not appear through the Borax, without being very much confus'd, ſo that they cannot be known; or rather, that we may perceive nothing beſides the Light, which enters into the Eyes irregularly.

When we immerge this Piece of Borax in the Oil, we perceive Objects in the ſame Manner through the Oil and Borax, as through the Oil alone; the Borax becomes in a Manner inviſible, and if there be any thing in the Borax, we perceive it, as if it were in the Oil.

2846. Therefore the Light paſſes in a right Line from the Oil of Olives into the Borax, and from the Borax into the Oil; and there is no Refraction here, although the Denſity of the Oil is to the Denſity of the Borax as 6 to 11; but the Actions are in this inverſe Ratio, with which all the Particles act upon the Light, and there is a Com-

* 2841. penſation made *.

2847. *Light often in it's Paſſage out of a more denſe Medium into a rarer is refracted towards the Perpendicular.* Which is contrary to Number 2787.

Expe-

EXPERIMENT 2.

We make uſe of the Glaſs Box M I *, which has been often us'd; into this we put the ſmaller Glaſs Box P (Fig. 7.) whoſe Bottom is of Braſs, and whoſe Conſtruction is not different from the Conſtruction of the greater Box before explain'd †. 2848. Pl. 90. Fig. 6, 7. * 2758. 2759. † 2759.

Inſtead of this ſmaller Box we may uſe a polygonous Phial whoſe upper Part is cut, as is repreſented at O (Fig. 7.) But in this Caſe, that we may avoid the irregular Reflections of the Light, as much as poſſible, the external Surfaces of the Bottom, and Sides, muſt be made rough by rubbing on them coarſe Sand, that they may receive a black Colour. We only leave the two greater, and oppoſite Sides *m* and *n* untouch'd, through which the Light muſt paſs. 2849.

This Box has this Inconveniency, that the Light can never paſs through the Sides of the Box quite regularly; becauſe the inner Surfaces are never entirely plane; which Inconveniency is nevertheleſs ſcarce ſenſible when Spirit of Turpentine is pour'd in, whoſe refracting Force is very great.

Water is pour'd into the Box I M to any Height; Spirit of Turpentine is pour'd into the Box P to the ſame Height. 2850.

The Light is tranſmitted through the Board *, which was made uſe of in the Experiments of the laſt Chapter; the Light is let into the larger Box at *a b* through the End M L, perpendicularly to the Surface; the Light enters into the Box P, which is ſet obliquely at *c d*; *c d* is in the Side *g* of the ſmaller Box, a little diſtant from the End, and the Light enters into the Oil very obliquely; it is refracted at *e f*, approaching towards the Perpendicular. We have not repreſented the Ray going out of the Box P, to avoid Confuſion. * 2768.

The Denſity of Water is to the Denſity of Spirit of Turpentine, as 8 to 7. The Sine of Incidence in Water is to the Sine of Refraction in the Spirit, as 11 to 10. Laſtly the Force, with which the Particles of Water act, is to the Force of the Particles of the Spirit of Turpentine, as 3 to 5. 2851.

When we compare the Forces, with which all the Particles of Bodies act, we conſider ſuch Particles, as contain equal Quantities of Matter; but we don't mean the ſmalleſt Particles, into which Bodies may be reſolv'd; for who can determine whether all theſe are equal or not; and whether the Action upon Light may not be varied, from the Diſpoſition of the ſmalleſt Particles among Particles of a ſuperior Order? 2852.

2853. We alſo meaſure *the Forces of all the Particles*, by conſidering their whole Action upon Light, whilſt it paſſes through the Space of Attraction; that is, *we compare* the whole Effects of the Attraction, and reaſon *as if all the Spaces of Attraction were equal*, which perhaps is not true; but this does not alter the Concluſions, which may be of uſe in explaining Phenomena.

2854. *When Light paſſes out of one Body into another, the Difference of the Forces only is to be conſider'd*; but we ſpeak of the whole Forces of Bodies, which we have by multiplying the Denſities by the
* 2841. Forces of all the Particles *. In this Caſe a ſmaller Action, acting contrary to a greater, diminiſhes it.

2855. *When Light paſſes through different Mediums, terminated by parallel Planes, the Direction in the laſt Medium is the ſame, as if the Light had paſs'd out of the firſt Medium immediately into the laſt.* For in each Caſe the whole bending Force is the ſame. The Difference between the Force of Air and the Force of Water, is to the Difference between the Force of Air and the Force of Glaſs, nearly as 14 to 25. If the Light paſſes immediately out of Air into Glaſs the bending Force will be equal to 25; but if the Light paſſes out of Air, through Water, into Glaſs, two Actions act ſucceſſively, the firſt of which is equal to 14; the ſecond is equal to
* 2854. the Difference between the Actions of the Water and Glaſs *, which is 11; and the Actions together are alſo equal to 25. If the Number of the Mediums put between be greater, the Demonſtration is the ſame; all the Differences of the intermediate Actions together are equal to the Difference of the Actions of the extreme Mediums. We ſuppoſe the Mediums to be terminated by parallel
* 2780. Planes, that all the Directions of the Actions may agree *.

2856. From hence we conclude that the Refraction out of one Medium into another may be determin'd, though there be no Experiments concerning ſuch a Paſſage; which will be ſufficiently illuſtrated by one Example only.

2857. Let us ſuppoſe the Sine of Incidence to be to the Sine of Refraction out of Air into Water, as 4 to 3: And that theſe Sines out of Air into Glaſs are, as 17 to 11, as has been obſerv'd be-
* 2811. fore *; I want to know the Ratio between theſe Sines, when the Light paſſes out of Water into Glaſs. If the Light ſhou'd paſs out of Air into Glaſs through Water, the Sine of the firſt Incidence wou'd be to the Sine of the ſecond Refraction, in the Ratio of 17 to 11. We ought to take away from this the firſt Refraction, in which the Ratio of the Sign is, as 4 to 3. By multiplying the

Antecedents

Antecedents and Conſequents we join the Ratios, which take Place together; after the ſame Manner by Diviſion we ſeparate the Ratios, when one is to be taken from the other; therefore the Ratio ſought is that, which is given between $\frac{17}{4}$, $\frac{11}{3}$, that is, the Sines, of which we are ſpeaking, are to one another, as 51 to 44. For this Ratio is requir'd, that the whole Inflection may be the ſame with that, which takes Place, when the Light goes immediately out of the Air into the Glaſs.

SCHOLIUM.

WE ſaid that from the Experiments concerning Refraction the Proportions of Forces were determin'd, with which the Particles of Bodies act upon Light *: I ſhall now ſhew how this is done; but firſt I ſhall ſpeak of the Forces of the Bodies themſelves, and then of the Forces of all the Particles. 2858. * 2837.

When we treat of the whole Forces of Bodies, the Light, which paſſes out of empty Space into Bodies, muſt be conſider'd; for if Light paſſes from one Body into another, we can only diſcover the Difference of the Forces of thoſe Bodies *; but all Caſes may be reſolv'd by the ſame Rule. 2859. * 2854.

We have already ſaid that it was unknown to us, whether all the Spaces of Attraction be equal or not *; we muſt moreover add, that it is alſo unknown to us, whether the Action, which is different at different Diſtances from the Surface of the Body, be alter'd according to the ſame Laws, in the Spaces of Attraction of all Bodies. But as the whole Effects alone, that is, the Alterations only, which obtain in the Paſſage through the Space of Attraction, are diſcover'd by us, we may reaſon, as if the ſame Laws obtain'd every where; in the ſame Manner as we ſuppos'd the Breadths of the ſaid Spaces equal *. But if the ſame Laws take Place, *the Forces are to one another, as they wou'd be, if they acted uniformly through the whole Spaces*, and we ought to Reaſon concerning theſe Forces as of any accelerating Forces whatever, which increaſe their Celerities uniformly, and act through equal Spaces. * 2853. 2853. 2860.

Let us ſuppoſe two Bodies, one of which deſcends vertically through AB, the other rolling down the inclin'd Plane AD; both theſe Bodies are accelerated equably; but they are driven with unequal Forces. 2861. Pl. 90. F. 8.

Let us ſuppoſe one to have come to B, and to be carried with the Velocity acquir'd in falling through AB, and to be accelerated in deſcending beyond BC; we ſuppoſe the ſecond Body to have come to D, and to be carried with the Velocity, acquir'd in running through AD, and to be accelerated in deſcending beyond DE, equal to BC. From the given Velocities the Forces are ſought.

Draw D*d*, E*e*, horizontal; the accelerating Forces will be as AD to A*d*, or AE to A*e* *; that is, as DE or BC, to *de* †. The Velocities at D and *d*, * 341. † 17, 18. El. 5.

* 390. D and *d*, as alſo at E and *e*, are equal *; therefore the four given Velocities, are thoſe, which the Body would acquire in falling through AB, * 374. AC, A*d* and A*e*; and in this Ratio are the Squares of theſe Velocities *. Therefore BC, is to *de*, that is, the Force, that accelerates the firſt Body, is to the Force, acting upon the ſecond, as the Difference of the Squares of the Velocities of the firſt Body to the Difference of the Squares of the Velocities of the ſecond Body.

2862. If we apply this to Light, we have this general Rule; *The Force, that accelerates Light, whilſt it paſſes from one Medium into another, is to the Force, which takes Place in another Paſſage, as the Difference of the Squares of the Velocities before and after the Ingreſs, in the firſt Motion, to the like Difference in the ſecond.*

2863. We have ſeen above that the Velocities of Light in Air and Water are to one another, as 3 to 4; the Velocities of Light in Air and Glaſs, as * 2811. 11 to 17 *. The Sine of the Incidence is to the Sine of Refraction in the Motion from Air into Spirit of Turpentine as 25 to 17; and therefore * 2810. the Velocities in theſe Bodies are as 17 to 25 *. From hence we deduce that the Velocities of Light in Air, Water, Glaſs, and Spirit of Turpentine, are to one another as 1000, 1333, 1547, 1470. The Velocity of Light in Air differs little from the Velocity in Vacuo, and unleſs we uſe greater Numbers, the Difference can't be expreſs'd; therefore we ſuppoſe the Velocity of Light in Vacuo to be 1000 alſo.

Now if any one ſeeks the Ratio between the whole Force of the Glaſs and the Action, which acts upon the Light, when this paſſes out of Water into Spirit of Turpentine, this Ratio is that, which is given between the Difference of the Squares of the Numbers 1547 and 1000, to the * 2862. Difference of the Squares of the Numbers 1470 and 1333 *; which Differences are as 1388 to 358.

The Forces of Bodies being given, the Forces of the Particles are eaſily diſcover'd; for as thoſe are in a Ratio compounded of theſe laſt Ra-2864. tios and the Denſities, it is manifeſt, that *the* ſaid *Forces of the Bodies muſt be divided by the Denſities, that the Quotient of the Diviſions may expreſs the Forces of the Particles.*

2865. From the Squares of the Velocities of Light in Water, Spirit of Turpentine, and Glaſs, I ſubſtract the Square of the Velocity in Vacuo, and the Differences are as 77^8, 1163, 1388, which expreſs the Forces of the * 2862. Bodies *; theſe being divided by the Denſities of thoſe Bodies, which are as 40, 35, 103, we have the Forces of the Particles as 195, 333, 135.

2866. The Force, that accelerates Light in it's Paſſage out of a leſs refracting Medium into a more refracting one, retards the Motion in the contrary * 2828. Paſſage *; whence it follows, that what is demonſtrated in this Scholium concerning the Acceleration of Light, may be applied to the Retardation of it, *mutatis mutandis*, when the Light paſſes out of a more refracting Medium, into a leſs refracting one.

CHAP.

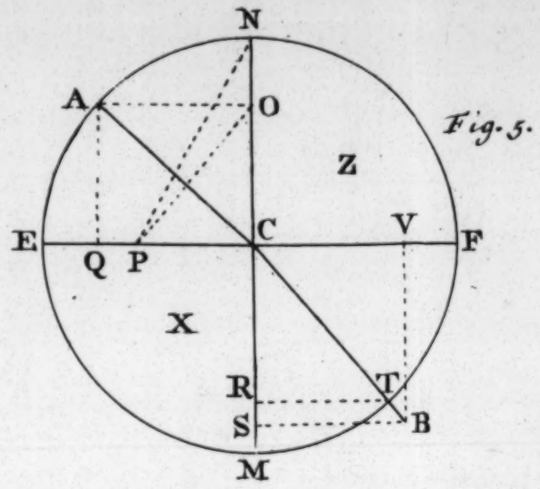


Fig. 5.

A B

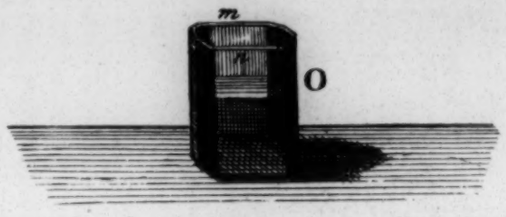
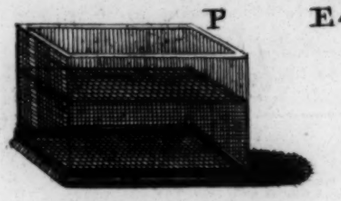


Fig. 7.



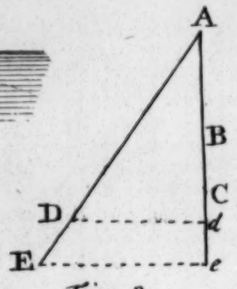
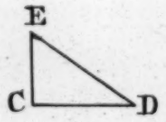


Fig. 8.

Fig. 3.



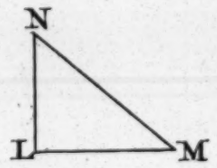
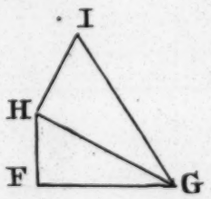


Fig. 4.



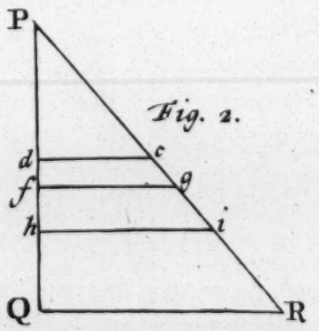


Fig. 2.



Fig. 1.

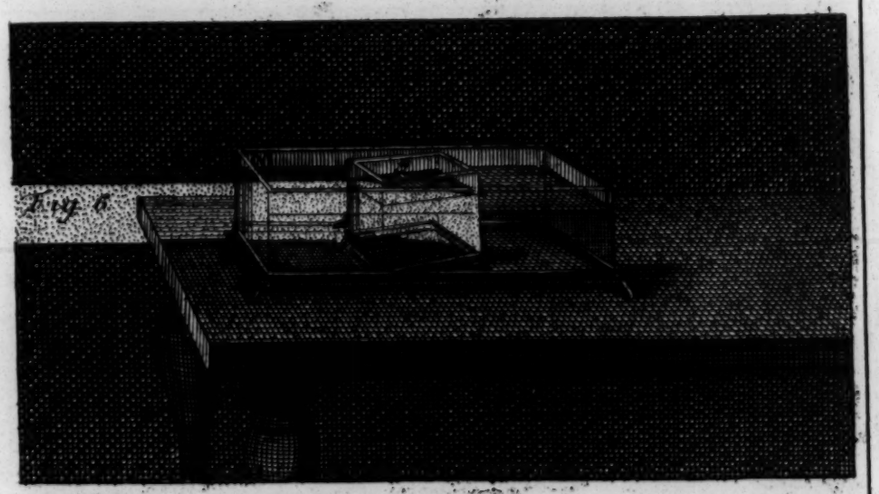


Fig. 6.

S. Mynde sc.

CHAP. VII.

Of the Refraction of Light, when the Mediums are ſeparated by a plane Surface.

THE Surfaces, that ſeparate the Mediums, may be varied *in infinitum*; we ſhall only examine thoſe that are plane and ſpherical. In the Rays alſo there may be Variations *in infinitum*; we ſhall only conſider thoſe Rays, which proceed from one Point, or tend to one Point, or are parallel. All theſe Things being conſider'd, we ſhall be able to explain the chief Phenomena of Light. 2867.

DEFINITION 1.

The Rays proceeding from one Point, or which are mov'd, as if they proceeded from one Point, are call'd diverging Rays. 2868.

Such Rays are continually diſpers'd more and more.

DEFINITION 2.

The Point, from which the diverging Rays proceed, is call'd the radiant Point, or ſimply the Radiant. 2869.

The Rays ſometimes move by Reflection, or Refraction, as if they proceeded from a Point, though they do not proceed from it, which we ſaid were call'd diverging Rays alſo *. In this Caſe, 2870. * 2868.

DEFINITION 3.

The Point, from which the diverging Rays ſeem to come, is call'd the Point of Diſperſion of ſuch Rays. 2871.

DEFINITION 4.

Thoſe Rays are more diverging, that make a greater Angle. 2872.

The more diverging the Rays are, the Diſtance between them being ſuppos'd the ſame, the leſs diſtant is the radiant Point, or the Point of Diſperſion, and the contrary. 2873.

DEFINITION 5 and 6.

The Rays that meet in one Point, or wou'd meet if continued, are call'd converging Rays; and thoſe are more converging, that make a greater Angle. 2874.

DEFINITION 7.

2875. *The Point of Concourſe of converging Rays is call'd the Focus.*

DEFINITION 8.

2876. *The Point in which the Rays, that converge, and are intercepted, or bent before their Concourſe, wou'd meet if continued, is call'd the imaginary Focus of theſe Rays.*

2877. *The more Rays converge, ſuppoſing the Diſtance between them to be the ſame, at the leſs Diſtance is the Focus, whether the true or imaginary one.*

We only conſider thoſe diverging, or converging Rays, that are a little diſpers'd, that is, which, in their Paſſage from one Medium into another, take up a ſmall Space in the Surface that ſeparates the Mediums.

DEFINITION 9 and 10.

2878. *If among theſe Rays there be one Perpendicular to the ſaid Surface, the Rays are ſaid to be direct; in every other Caſe they are ſaid to be oblique.*

2879. *If parallel Rays paſs out of any Medium whatever into another of a different Refrangibility, theſe being ſeparated by a plane Surface, after the Refraction they are parallel alſo:* Becauſe they are all equally bent.

EXPERIMENT 1.

2880. In this Experiment, as in all of this Chapter, we let the Light
* 2794 2795. into a dark Place, as has been before explain'd *. We intercept
† 2769. the Rays with the Board †, and only tranſmit ſome of them through an horizontal Slit, which is determin'd at Pleaſure. We
* 2758.2749. make uſe of the Box terminated by Glaſs Planes *, and diſpos'd
† 2796.2767. as in the firſt Experiment of the fifth Chapter †; or we make uſe of the Glaſs ſolid *, diſpos'd as in the fourth Experiment of the ſame Chapter. Howſoever the Rays enter the Water or Glaſs, or go out of theſe Bodies, if they all paſs through the ſame Surface, they remain parallel.

2881. Let there be the Mediums X and Z, this the leſs, that the more
Pl.91.F.1. refracting, ſeparated by the Plane E S; let the diverging Rays R C, R *b*, R *a*, proceed from the Point R, and enter the more refracting Medium: Among theſe let R C be perpendicular to the

Surface E S; this is not turn'd out of it's Way *, and it continues it's Motion along C G. The Rays R *b*, R *a*, undergo a Refraction towards the Perpendiculars, which we ſuppoſe drawn to the Surface E S in the Points *b* and *a*. * 2793.

We eaſily determine the Refraction of any ſuch incident Ray. Let R M be a Ray proceeding from R; O R C the Perpendicular, through R, to the Surface ſeparating the Mediums; take M O, and let it be to M R, as the Sine of Incidence to the Sine of Refraction; that is, as the Co-ſecant of Refraction to the Co-ſecant of Incidence *. By this being applied from the Point M, in the Angle M C R, the Point O is determin'd; from which the Line M N muſt be drawn through M, and this will co-incide with the refracted Ray. 2882. * 2813.

Y M V being drawn perpendicular to E S, at M, the Angle of Incidence is V M R; the Angle of Refraction is Y M N, to which V M O is equal *. If we ſuppoſe a Circle deſcrib'd with the Center M, and Semidiameter M C, the Lines M O, M R, will be Co-ſecants of the Angles of Refraction and Incidence; whence it appears that the refracted Ray M N was well determin'd. 2883. * 15. El. 1.

But if the diverging Rays be direct, and a little diſpers'd, ſuch as we have ſhewn the Rays R C, R *b*, R *a*, to be, we reaſon in the ſame Manner; R *a*, *r a*, being ſuppos'd to be in the ſaid Ratio of the Co-ſecants, *a* A will be the refracted Ray; but as C *a* is ſmall, the Rays R *a*, R C, do not differ as to Senſe, neither do *r a*, *r* C; therefore R C, *r* C, are alſo in the ſame conſtant Ratio of the Co-ſecants, wherefore the Ray R *b*, as alſo the reſt a little diſpers'd, are refracted as if they proceeded from the ſame Point *r*, and *r* is the Point of Diſperſion of the refracted Rays. 2884.

And *in this Caſe, in which the Rays paſs from a leſs refracting Medium into a more refracting one, the diverging Rays become leſs diverging* *; and the Diſtance of the Radiant from the Surface is to the Diſtance of the Point of Diſperſion, as the Sine of Refraction to the Sine of Incidence. 2885. * 2872.

Experiment 2.

We cloſe the open End of the Box A D * with the Board T †. The Rays, which paſs through the Glaſs V are converging, they mutually interſect one another at R, and become diverging. We don't enquire here, how the Glaſs produces this Effect, we ſhall ſpeak of this Motion of Light in it's proper Place; it is ſufficient that there are diverging Rays, that we may demonſtrate the Experiment. 2886. Pl. 191. Fig. 2. * 2765. † 2770.

We let theſe diverging Rays enter directly into the Glaſs ſolid
* 2767. C *, and we immediately perceive the Rays to move in the Cube, as if they proceeded from a more diſtant Point.

2887. We reaſon about converging Rays in the ſame Manner. Let
Pl.91.F.1. P Q be a Ray, which, ſuppoſing the ſame Medium Z and X, is directed towards a given Point *f*; T *f* D H being drawn through *f*, perpendicular to the Surface ſeparating the Mediums, if Q T be to Q *f*, as the Co-ſecant of Refraction to the Co-ſecant of Incidence, Q T will be the refracted Ray, as follows from what is demon-
* 2883. ſtrated before *.

2888. *If the Rays be direct, a little diſpers'd, and converging, and paſs into a more refracting Medium, they become leſs converging.* The Rays, among which H D, as I *i*, L *l*, which are directed to the imaginary Focus *f*, meet at the true Focus F, at a greater Diſtance;
* 2884. which appears, if we reaſon as about diverging Rays *.

Experiment 3.

2889. This Experiment is made as the foregoing; the Situation of the
Pl.91.F.3. Glaſs Cube C is alter'd, and the Glaſs of the Board is rais'd in ſuch
* 2771. Manner *, that the Rays may paſs over the Cube; theſe meet at *f*, and this Point of Concourſe remains at the ſame Diſtance from the Board, whether the Glaſs be rais'd or depreſs'd.

But this being depreſs'd in ſuch Manner, that the converging Rays may enter into the Cube, the Concourſe is immediately remov'd as far as F.

2890. The Rays are mov'd along the ſame Lines, from what Part
* 2789. ſoever they proceed *; therefore from the Demonſtrations concerning Motion, out of a leſs refracting Medium into a more refracting one, we deduce what relates to contrary Motion.

2891. The *diverging Rays in a more refracting Medium* X, *proceeding*
Pl.91.F.1. *from a Point* F, are mov'd, *in a leſs refracting Medium* Z, as if
2892. they proceeded from *f*, that is, they *become more diverging*; the *converging Rays*, which tend to *r*, meet at R, and *become more converging*.

Experiment 4.

2893. All Things being order'd as in the two laſt Experiments; the
Pl.91.F.4. Glaſs Cube C is ſo plac'd, that the radiant Point R, which the Rays paſſing through the Glaſs of the Board T make, may be in the Surface of the Cube; then the diverging Rays paſs through the Cube, and entering the Air are diſpers'd more.

Expe-

EXPERIMENT 5.

All Things remaining, as in the foregoing Experiment, move the Cube C to the Board T in ſuch Manner, that the converging Rays may paſs through the whole Cube; they then become more converging in the Air, and meet at F, at a ſmaller Diſtance than if they had continued their Motion, as they move in the Glaſs. 2894. Pl.91.F.5.

If the Rays, although direct, be too much diſperſed, what we ſaid of the Points of Diſperſion, or the Focuſſes, cannot be applied to the Points; but a ſmall Space is conceiv'd, through which the Rays paſs, which is the greater, the more the Rays are diſpers'd. 2895.

What relates to oblique diverging Rays, or converging, is more difficult; therefore we ſhall only mention it, and demonſtrate it in the following Scholium. 2896.

Let B E be the Separation of the Mediums Z and X, that of the leſs, this of the more refracting one. We ſuppoſe the Plane of the Figure to be perpendicular to the Surface B E, as it always is, when the Surface is repreſented by a Line. 2897. Pl.91.F.6.

Let us ſuppoſe Rays, a little diſpers'd, to proceed from A; and among theſe A B to be given; and that therefore they paſs obliquely out of Z into X; C A E being drawn perpendicular to B E, through A, let the Point D be ſought, through which the refracted Ray B I would paſs, if continued downwards *; the Point of Diſperſion of the refracted Rays will be in this Line at F, which Point is determin'd by the following Conſtruction. * 2882.2887.

We draw E H, E L perpendicular to A B and D B, from E; through H, where the Perpendicular to the incident Ray cuts it, we draw H N parallel to A E, cutting the other Perpendicular at N; the Points N and D being join'd, we draw L C parallel to N D, which meets D E continued at C; C F being drawn parallel to B E, the Point ſought F will be given in the Concourſe of this Line with the Line B D, it being produc'd as much as is neceſſary. 2898.

We ſhall demonſtrate in the following Scholium, that the neighbouring Rays A B, A *b*, are refracted along B I, *b i*, as if they proceeded from F; but the Demonſtration only regards the Plane of the Figure. But we ſuppoſe Rays proceeding from A to be ſo diſpers'd, as that they may make a Cone or Pyramid. Now if we conceive another Plane, that paſſes through the Line C A D, and makes a ſmall Angle with the Plane of the Figure, this Plane will paſs through the ſaid Cone or Pyramid; that is, ſome of the Rays, proceeding from A, will be in this Plane; for theſe, a Point as F, 2899. Pl.91.F.7.

will be determin'd in the laſt Plane by help of the ſame Point C; and all the Points as F, which are found for the whole Cone or Pyramid, make a ſmall Portion of the Circumference of a Circle, whoſe Center is C, and which is parallel to the Surface E B; and this ſmall Portion of the Circumference may be look'd upon as a ſmall right Line, perpendicular to the Plane of the Figure.

2900. Where we ſpoke of direct Rays, we conſider'd four Caſes *; we
* 2885.2888. 2891.2892. have now applied one of theſe to oblique Rays only; but the Demonſtrations may be applied to all Caſes. What was ſaid of the Rays A B and D B, belongs to any incident Ray whatever with it's refracted Ray, whether this be the refracted Ray itſelf, or only a Continuation of it, as in the preſent Example; alſo it matters not, whether the Angle of Incidence exceeds the Angle of Refraction, or the contrary, the ſame Conſtruction may take place, and the other Demonſtrations obtain in the ſame manner.

2901. Therefore in General we infer, that *oblique Rays, whether diverging or converging, that paſs out of one Medium into another, theſe being ſeparated by a plane Surface, do not move after Refraction as if they proceeded from a Point, nor as if they tended towards one Point*; *that is*, that *there is no Point of Diſperſion, or Focus of the oblique Rays*; *how little ſoever the Rays are diſpers'd.*

2902. In theſe Caſes, as was ſaid of direct Rays too much diſpers'd *,
* 2895. for the Point of Diſperſion, or Focus, we have a ſmall Space, through which all the Rays paſs; but we muſt determine where this ought to be plac'd. As at F the Rays paſs through the ſmall Line, ſo alſo at D, and between theſe Points is the Place ſought.

2903. If this Line be cut by a plane Perpendicular to D F, the ſmall
Fig. 6. Space, of which we are ſpeaking here, will in this Plane have the Figure of a Rectangle, whoſe Sides will have a different Ratio to one another, according to the different Place, in which this Plane is fix'd. But there is no Reaſon why we ſhould chuſe a ſmall Space whoſe Height exceeds it's Length, than the contrary; therefore this Plane muſt be conceiv'd in that Place, in which the Space is a Square, and we ſhall have this Place for the Point of Diſperſion, or Focus of the Rays: This Place is different according to the different Diſperſion of the Rays, proceeding from A.

2904. Let us ſuppoſe the Rays proceeding from A, to make a right Cone; take B P equal to E H, and E Q equal to E L; draw Q C and P D, which laſt, continued, cuts F C at S. Through D draw a parallel to B E; and from the Point T, in which that cuts Q C,

another

another Line T S muſt be drawn; and this will cut DF in the Point ſought V.

But if the diverging Rays make an oblique Cone, whoſe Baſe is in the Surface itſelf that divided the Mediums, which obtains, when the Rays are intercepted in the Surface, and there only go through a leſs, circular Hole. The Point ſought is in the mutual Section of the Lines BF and QC, all which is demonſtrated in the following Scholium. 2905.

SCHOLIUM.

The Demonſtrations concerning the Refraction of oblique Rays.

WE ſaid that the neighbouring Rays AB, A*b*, refracted along BI, *b i*, would meet at F, if continued downwards; we muſt now demonſtrate that the Point F was well determin'd *. 2906. Pl. 91. F. 7. * 2898.

With the Center F, at the Diſtances FD, FB, are deſcrib'd the Arches D*r*, B*g*; becauſe theſe are ſmall, they may be looked upon as right Lines perpendicular to F*b*. In the ſame Manner the Arch B*o*, decrib'd with the Center A, at the Diſtance AB, may be look'd upon as a right Line perpendicular to A*b*.

The Line NH muſt be continued as far as M. From the Similitude of the Triangles we deduce the Proportions *; but we have the ſimilar Triangles DBE, EBL, DEL†, *d*D*r*, B*bg*; ABE, EBH, B*bo*, are alſo ſimilar; and alſo BAD, BHM; and laſtly FB*g*, FD*r*. * 4. El. 6. † 8. El. 6.

From what is demonſtrated concerning Refraction * it follows, * 2883.

AB : BD :: A*b* : *bd*.

By Altern. and Inverſ. A*b* : AB :: *bd* : BD.

By Diviſion and Alternation, A*b* — AB = *bo* : *bd* — BD = *bg* + *dr* :: AB : BD :: BH : BM.

By Compariſon of the Triangles we have, *bg*, B*b*, *bo*, and BL, EB, BH, in ordinate Proportion;

Therefore by Equality * *bg* : *bo* :: BL : BH; * 22. El. 5.

But we had *bo* : *bg* + *dr* :: BH : BM;

Therefore again by Equality, *bg* : *bg* + *dr* :: BL : BM;

By Inverſ. and Diviſ. *dr* : *bg* :: BM — BL = LM : BL.

Therefore D*r*, *dr*, *bg*, LM, BL, EL, are in perturbate Proportion; for

D*r* : *dr* :: BL : EL;

And by Equality perturb. D*r* : *bg* :: LM : EL *. * 23. El. 5.

The Triangles alſo give *bg* : B*g* :: EL : LD;

Therefore by Equality D*r* : B*g* :: LM : LD :: LN : LE;

In which ſame Ratio are FD, FB; becauſe D*r* : B*g* :: FD : FB.

But in the ſixth Figure we have this very Ratio; for

LN : LE :: CD : CE :: FD : FB;

and it is manifeſt that the Point F was well determin'd.

If

2907. If we conceive the Plane of the Figure to turn about the Axis CE, the Rays AB, A*b* will make Cones, which will have the ſame Axis AE; all the Rays, which proceeding from A, paſs between the ſaid conical Surfaces, which are refracted, being continued backwards, tend through D*d*, to Points as F, which all together make a Circle; which the Point F has deſcrib'd, in the ſaid Revolution of the Plane.

Now when the Rays proceeding from A are diſpers'd a little, they may all be conſider'd, as if they were of thoſe, which are thus contain'd between the ſaid Surfaces, whence follows what has been demonſtrated
* 2890. above *.

2908. We may conceive the Cone, which the Rays a little diſpers'd make, plac'd in ſuch Manner, that it may be beneath the Plane of the Figure, and may touch it; then the ſmall Line at F, through which the Rays
* 2899. paſs *, is all above the Plane; and all the Rays between D and F make a Pyramid whoſe Baſe is D*d*F, and Vertex the upper Point of the ſmall Line at F.

The Triangle D*rd* is infinitely ſmall in reſpect of FD*d*; therefore, inſtead of the ſaid Baſe we may have the Triangle FD*r*. Now to demonſtrate what was ſaid of determining the Point, which is had for the
* 2904. 2905. Point of Diſperſion, or Focus *, we muſt determine the Ratio, which is given between D*r* and the ſmall Line, which determines the Height of the Pyramid, which we ſhall call *a*.

2909. Let us firſt ſuppoſe the diverging Rays to make a right Cone, whoſe Section, in the Surface ſeparating the Mediums, is an Ellipſe, whoſe greater Axis is equal to B*b*, and whoſe leſs Axis is perpendicular to the Plane of the Figure, and equal to B*o*.

We ſet aſide B*b*, and conſider B*g*, whoſe Magnitude that determines.

As FB is to FD, or CE to CD, ſo is B*g* to D*r*.

As DB is to DF, or DE to CD, ſo is B*o* to *a*;

becauſe the Vertex of the ſimilar Triangles, from which the Proportion is deduc'd, is given between D and *d*.

2910. If inſtead of the ſmall Lines B*g*, B*o*, we take others which have the ſame Ratio as theſe, the laſt Terms of theſe Proportions will give us Lines, which will be to one another as *dr* and *a*.

2911. The ſimilar Triangles give B*g*, B*b*, B*o*, and EL, EB, EH, in ordinate Proportion whence

by Equality B*g* : B*o* : : EL : EH.

We have alſo (*Fig.* 6.) CE : CD : : EQ=EL : DT.

* 8910. and DP : SD : : DE : CD : : BP=EH : FS.

2912. Therefore DT : FS : : *dr* : *a**.

2913. If we conceive the Pyramid above-mention'd *, cut at V, we diſcover
* 2908. the Breadth of this Section by this Proportion:

DF, FV : : DS, S*y* : : D*r*, to the Breadth.

We have the Height by this Proportion,

DF, DU : : DS, D*y* as *a*, to the Height.

Inſtead

Inſtead of *dr* and *a*, Quantities being put in the ſame Ratio of DT to FS *, we diſcover the fourth Term of both Proportions to be V*y*; whence it follows, that the Section makes a Square, and that it was well determin'd in the Conſtruction *. * 2912. * 2904.

If the diverging Rays make an oblique Cone, whoſe Baſe is in the Surface itſelf, which ſeparates the Mediums, and the Diameter of the Circle equal to B*b*, this ought to be taken for a ſmaller Axis of an Ellipſe; that is, what was ſaid of B*o*, muſt be applied to B*b*; and therefore inſtead of EH we ought to make uſe of BE *; then the Point P falls on E, and PS and EC are confus'd, as alſo ST and CT, and the Point V is had in the mutual Section of the Lines BF, QC, as has been ſhewn in N. 2905. 2914. * 2911.

CHAP. VIII.

Of the Refraction of Light, when the Mediums are ſeparated by a ſpherical Surface.

WE have many Caſes to be examin'd, which I ſhall briefly conſider; I ſhall firſt ſhew in general what belongs to this Motion, and ſhall afterwards add ſome Things in particular. 2915.

Let Z and X be Mediums ſeparated by a ſpherical Surface, whoſe Center is C, the firſt the leſs, the laſt the more refracting. Pl. 95. F. 1,2,3,4.

The incident Ray, that paſſes through the Center, or would paſs through if continued, is not turn'd out of it's way by Refraction *; for *a ſpherical Surface may be looked upon as conſiſting of innumerable ſmall Planes*, which are perpendicular to the Extremities of the Diameters. 2916. * 2793. 2917.

Therefore the Angles of Incidence and Refraction are thoſe, which the incident, or refracted Rays, make with ſuch Lines. 2918.

Let NM be the incident Ray; the refracted Ray is ſought. Through the Center C draw CM, as alſo BCD, parallel to the Ray NM; and the Point *d* being taken at Pleaſure, we muſt apply the Line *dm* in the Angle MC*d*, which is to *d*C, as the Sine of Incidence to the Sine of Refraction; and the refracted Ray MD, or M*d*, will be parallel to *md*. 2919.

MC makes an Angle with CD obtuſe on one Side, and acute on the other; when *dm* exceeds *d*C, that is applied in the obtuſe Angle; otherwiſe, we make uſe of the acute Angle; this always happens in the Paſſage out of a more refracting, into a leſs refracting Medium. 2920.

If

2921. If in this Caſe *d m* be not long enough, that the Application may be made, the Refraction is impoſſible, and the Ray does not paſs into a leſs refracting Medium. In this Caſe if from the known Angle of Incidence, we ſeek the Angle of Refraction by Compu-
* 2809. tation *, we find it to be greater than a right Angle; which ſhews the Refraction to be impoſſible.

2922. We made *m d*, *d* C proportional to the Sines of the Angles of Incidence and Refraction, which are as M D, D C; whence we deduce that the refracted Ray was well determin'd, if we attend to the two Things that follow.

2923. That *in every Triangle, the Sines of the Angles are proportional to*
2924. *the oppoſite Sides: And* that *any Angle with it's Complement to two right ones has the ſame Sine.*

2925. Whence it follows that in the Angle M D C, the Sides M D, D C are to one another, as the Sines of the Angles M C D, or M C B, and C M D; which Sines therefore are, as the Sines of Incidence to the Sine of Refraction; but the Angle M C B is
* 29. El. 1. equal to the Angle of Incidence *; therefore C M D is the Angle of Refraction, or it's Complement to two right ones.

2926. When the Point D falls in the Medium, in which the incident Ray is given, as happens, when the Convexity of the Separation is given on the Side of the more refracting Medium, the refracted Ray is not the Line D M itſelf, but the Continuation of it.

2927. Hence we deduce, how *direct parallel Rays, a little diſpers'd*, are refracted *in their Paſſage out of one Medium into another, if theſe be ſeparated by a ſpherical Surface.*

The Ray A B is not bent; *a b* is refracted, and becomes *b* F, or *b f*; and *b* F is to F C, as the Sine of Incidence to the Sine of Refraction; but as B *b* is ſmall, B F and *b* F are equal to Senſe. If therefore F be determin'd in ſuch Manner, that B F be to F C in the ſaid Ratio of the Sines of Incidence and Refraction, F will be the Focus, or Point of Diſperſion, of all the refracted Rays parallel to A B, and with which this is ſurrounded at a ſmall Diſtance. Theſe refracted Rays *are converging, when the Convexity of the Separation is given on the Side of the leſs refracting Medium,* then they meet at F. *In a contrary Diſpoſition of the Surface they*
2928. *are diverging*, and are mov'd, as if they proceeded from F *.
* 2926.

2929. We ſhall now conſider in general all the different Caſes of Rays that are direct and a little diſpers'd.

With regard to all we muſt obſerve that the Rays which proceed from a Point, or tend towards a Point, which we affirm to belong to

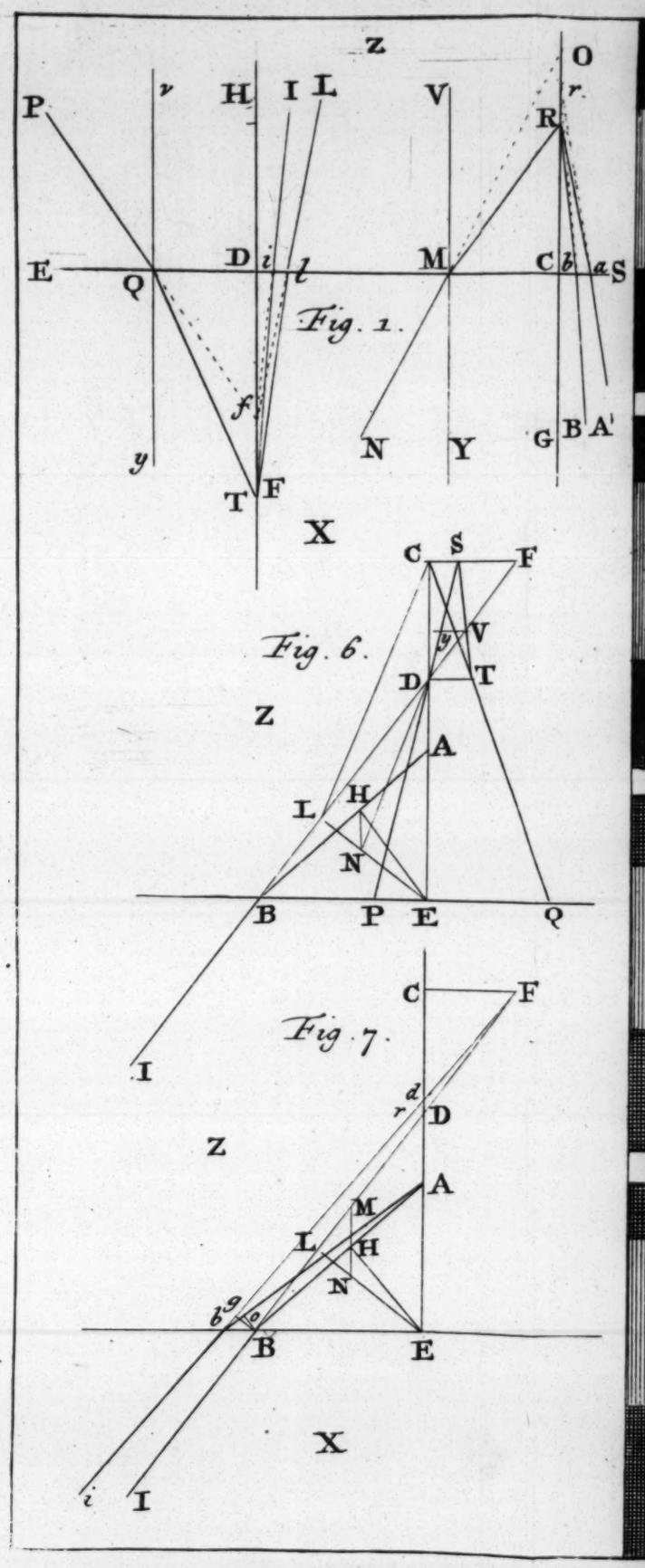


Fig. 1.

Fig. 6.

Fig. 7.

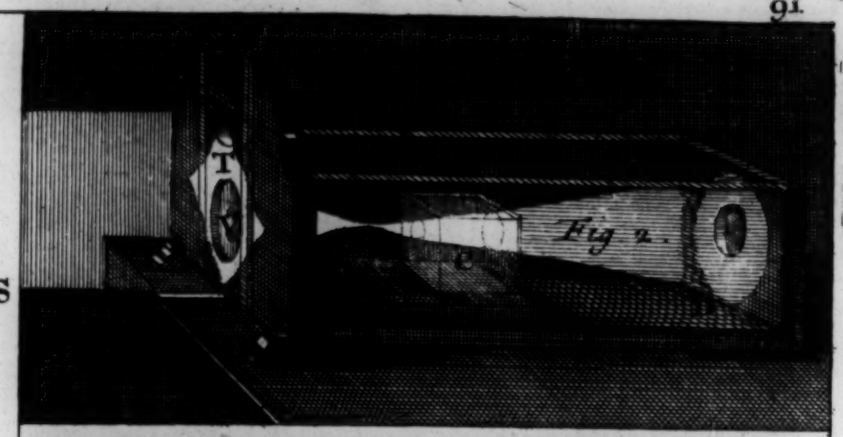


Fig. 2.

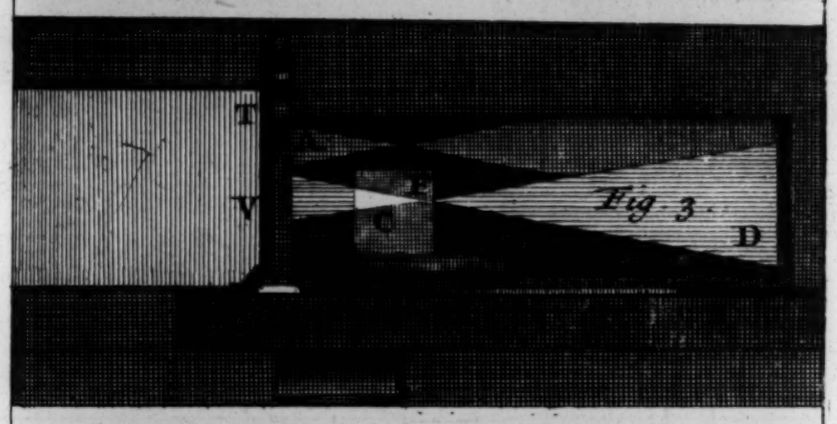


Fig. 3.

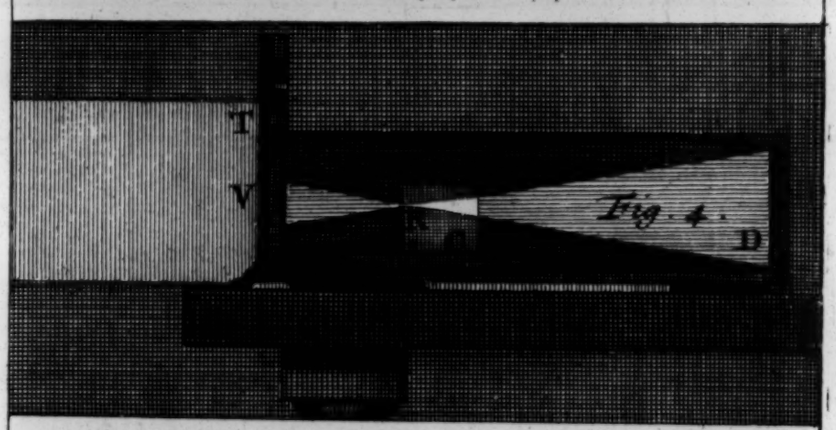


Fig. 4.

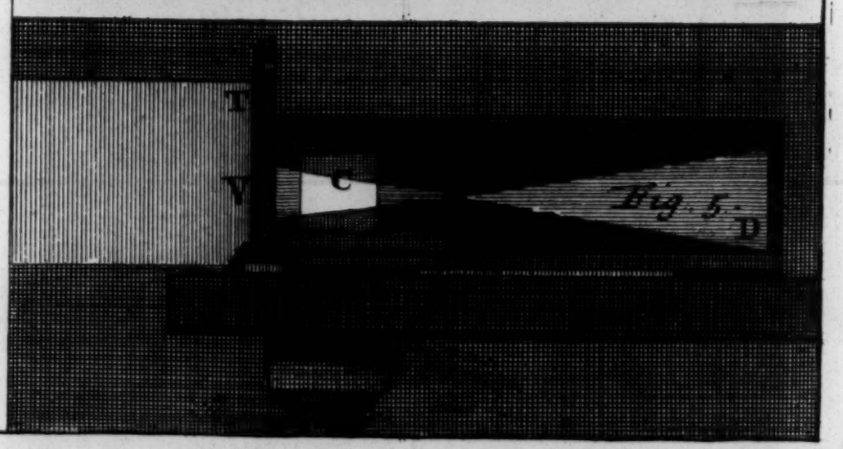


Fig. 5.

to one Point, are mov'd after Refraction, to Senſe, as if they alſo belong'd to one Point as has been demonſtrated of parallel Rays; which will be ſeen in the firſt Scholium following; in which we ſhall demonſtrate a general Rule to determine the Refraction in all Caſes; which we ſhall be able to expreſs more ſimply, if we call the Point, to which the Rays come, the Point of theſe Rays. But this is the Rule.

2930. *The Diſtance between the Point of the incident Rays and the Point of the refracted parallel Rays, proceeding from a contrary Part, is to the Diſtance between the ſame Point of the incident Rays and the Surface, that ſeparates the Mediums, as the Diſtance between the ſaid Point of the parallel Rays, proceeding from the contrary Part, and the Center of the Surface to the Diſtance between the Surface and the Point of the refracted Rays.*

2931. Let Z be the leſs refracting Medium, X the more refracting one; R the Point of the incident Rays, whether it be the Radiant of diverging Rays, or the imaginary Focus of converging ones; let E be the Focus *, or Point of Diſperſion †, of parallel Rays proceeding from contrary Parts; C the Center of the Surface B V, that ſeparates the Mediums; laſtly let F be the Point of refracted Rays, that is, the Focus of converging Rays, or the Point of Diſperſion of diverging ones. According to the Rule *, R E is to R V, as E C to V F; with regard to which Proportion it muſt be obſerv'd, that V F is put at the ſame Part with E C, when R E and R V are at the ſame Part of the Point R, but if R falls between E and V, let E C and V F be taken towards contrary Parts.

Pl. 99. Fig. 5, 6, 7, 8.

* 2927. † 2928. * 2930.

2932. The ſame four Figures are of Uſe, in conſidering contrary Motion; then F is the Point of the incident Rays and R the Point of the refracted Rays; but then inſtead of E we ought to make uſe of *e*, the Focus of parallel, oppoſite Rays, and the Proportion is alter'd into this, F *e* is to F V, as *e* C is to V R.

2933. If, neglecting the accurate Determination of Refraction, we wou'd conſider all the Caſes ſeparately, we ought only to have regard to this, whether the Refraction be towards the Perpendicular, or from it, and we ſhall eaſily diſcover what follows.

2934. *If the Light paſſes out of a leſs refracting Medium, into a more refracting one, theſe being ſeparated by a ſpherical Surface, whoſe Convexity is towards the Part of the firſt Medium,* theſe Things obtain.

Parallel Rays become convergent.

Experiment 1.

2935. We join together the two Boxes D A *, and P † in ſuch Manner, that the convex Surface of the Glaſs V may be outwards, this laſt Box is fill'd with Water. We make uſe of an horizontal Ray, as in the Experiments of the two laſt Chapters.

Pl. 92. Fig. 1.

* 2765. The Light enters the firſt Box through the Hole *d*, and the parallel Rays make a Cylinder, which diſtinctly appears by Means of white Powder *. Theſe Rays go through the convex Surface into the Water, become converging, and meet at F.

† 2761.

* 2801.

2936. *Diverging Rays, the Radiant being remov'd enough, become converging alſo; but the Radiant approaching, the Focus is remov'd, and the contrary.*

Experiment 2.

2937. All Things remaining as in the foregoing Experiment, we make uſe of the Board T *, that is furniſh'd with a Glaſs, which collects the Sun's Rays at the Diſtance of four or five Inches: Then the Rays make the Radiant Point R, and diverging, go through the convex Surface into the Water; they become converging, and meet at the Focus F; which, when it is remov'd by a removal of the Board T, or brought nearer, the Radiant R is agitated with a contrary Motion.

Pl. 92. Fig. 2.

* 2772.

2938. *The radiant Point may be brought ſo near* the Surface ſeparating the Mediums, that the Focus will recede to an infinite Diſtance, that is, *that the refracted Rays will become parallel.*

Experiment 3.

2939. Things being order'd as in the laſt Experiment, the Board T muſt be mov'd gently in ſuch Manner, that the Focus may recede, by the approaching of the Radiant R, and the Poſition is eaſily diſcover'd, in which the refracted Rays are parallel.

Pl. 92. Fig. 3.

2240. *If the Radiant Point* R *is brought nearer, the refracted Rays will become diverging, yet leſs diverging than incident Rays.*

Experiment 4.

2941. In this Experiment the Board T is at a leſs Diſtance from V, than in the laſt, in other Things they agree; but the Rays are diverging in the Water, but leſs than in the Air.

Pl. 92. Fig. 4.

2642. *If the incident rays are converging, and tend to the Center of the ſpherical Surface, they undergo no Refraction.*

If

If they be directed towards another Point, as they are refracted towards the Perpendicular *, the Rays are ſo bent, that the Focus of theſe converging Rays is always given between the Center of the Surface ſeparating the Mediums, (towards which all the Perpendiculars are directed) and the Point, towards which the incident Rays tend. That is, *if the imaginary Focus of the incident Rays be at a leſs Diſtance than the Center, the refracted Rays are leſs converging: If this imaginary Focus be beyond the Center, the refracted Rays will be more converging.* 2943. * 2787.2840.

The laſt of theſe Caſes only is well repreſented in the Experiment.

Experiment 5.

This Experiment alſo differs from the foregoing ones only in the Poſition of the Board T, for if T be mov'd nearer to the Surface V, which ſeparates the Water from the Air, the converging Rays will enter into the Water; now if this Board be ſo diſpos'd, that the Rays may be directed to the Point, that is at a greater Diſtance from the Surface, than the Center of it, the refracted Rays will be more converging. 2944. Pl.92.F.5.

Now *if we ſuppoſe the Surface* to be turned, and *to be convex on the Side of the more refracting Medium, and the Light to paſs out of a leſs refracting into a more refracting Medium, as in the foregoing Caſes*, the Phenomena are diſcover'd in the ſame Manner, by conſidering that the Refraction is towards the Perpendicular. 2945.

Parallel Rays become diverging.

Experiment 6.

Things being order'd as in the firſt Experiment the Box P is turn'd in ſuch manner, that the Rays may go through the convex Surface, which is towards the Water, into it; the Rays will be diverging in the Water. 2946. Pl.92.F.6.

If the Rays be diverging, and the Radiant be in the Center of the Surface, that ſeparates the Mediums, the Rays are not bent by Refraction. 2947.

If the Radiant be at a leſs Diſtance from the Surface, the refracted Rays will be leſs diverging. But *if the radiant Point be more remov'd from the Surface than the Center, the refracted Rays are more diſpers'd than the incident Rays.* Which is confirm'd by Experiment. 2948.

Experiment 7.

The Box P remaining in the Poſition mention'd, the reſt agrees with the ſecond Experiment *; and the diverging Rays become more diverging, whilſt they go into the Water. 2949. Pl.32.F.7. * 2937.

2950. *If the Rays be converging, and the imaginary Focus be in the more refracting Medium at a ſmall Diſtance from the Surface ſeparating the Mediums, the refracted Rays converge* alſo, *but leſs than the incident Rays.*

If the imaginary Focus of the incident Rays recedes more, that
2951. is, *if the ſaid Rays converge leſs, the refracted Rays will alſo converge leſs, till, by the receding of the imaginary Focus, the refracted Rays are parallel.*

2952. *In a greater Receſs of the imaginary Focus, the refracted Rays become diverging.*

Experiment 8.

2953. All Things being order'd, as in the laſt Experiment, move the
Pl. 92. F. 8. Board T towards the Surface in ſuch Manner, that the converging Rays may enter into the Water, and the imaginary Focus may be at a ſmall Diſtance from the Surface, the refracted Rays become leſs converging, and meet at F.

2954. If the Board be brought nearer and nearer the Focus recedes, and
Pl. 92. F. 9. the refracted Rays will become parallel.

2955. And theſe are diverging, if the Convergency of the incident
Pl. 92. Rays be yet diminiſh'd more.

Fig. 10. After the ſame Manner we determine, what obtains *in the Paſ-*
2956. *ſage out of a more refracting Medium into a leſs refracting one*; and firſt indeed *if the convex Surface be given towards the leſs refracting Medium.*

Parallel Rays after Refraction meet in the Focus.

2957. *The Rays that come from a radiant Point, do* alſo *meet in the* Point or *Focus*; *and as this Point is brought nearer, the Focus goes farther off, and contrariwiſe.*

2958. *The radiant Point may be ſo plac'd,* that the Focus will fly off to an infinite Diſtance, *that* is, *the refracted Rays will become parallel.*

2959. *If the radiant Point be brought nearer, the Rays* that *are refracted* will diverge; *but yet leſs than the incident Rays, if the radiant Point be more diſtant from the Surface than the Center.*

2960. But *if the radiant Point be between the Surface and Center, the refracted Rays will be more diverging.*

2961. *If the Rays are converging, they become more converging in every Caſe.*

Expe-

Fig. 1.

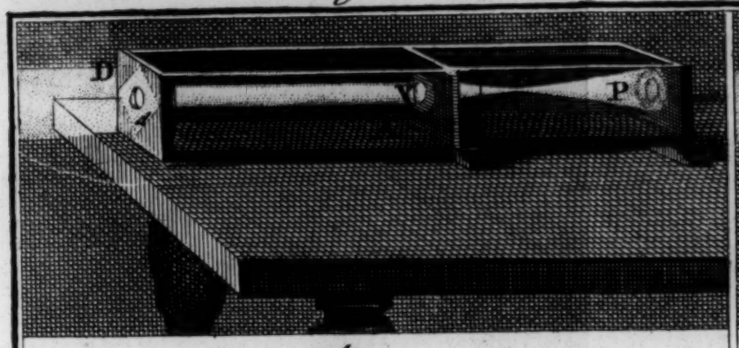


Fig. 2.

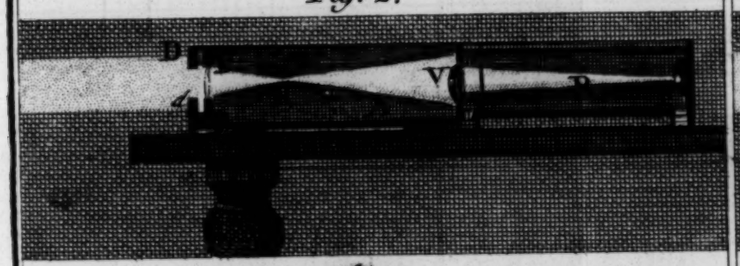


Fig. 3.

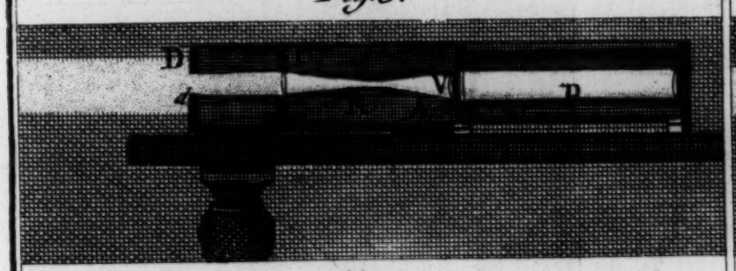


Fig. 4.

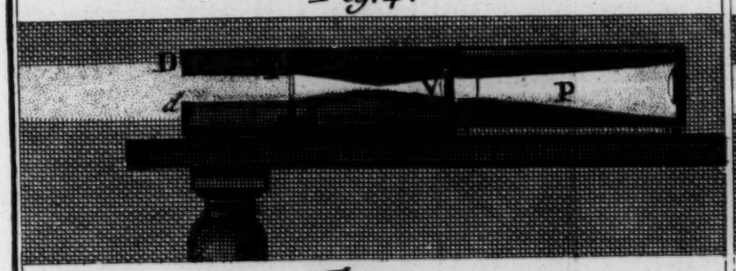


Fig. 5.

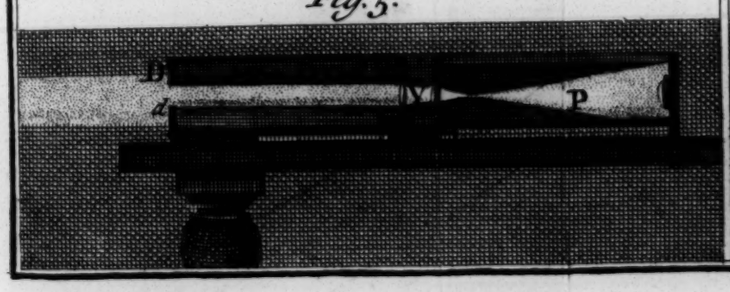


Fig. 6.

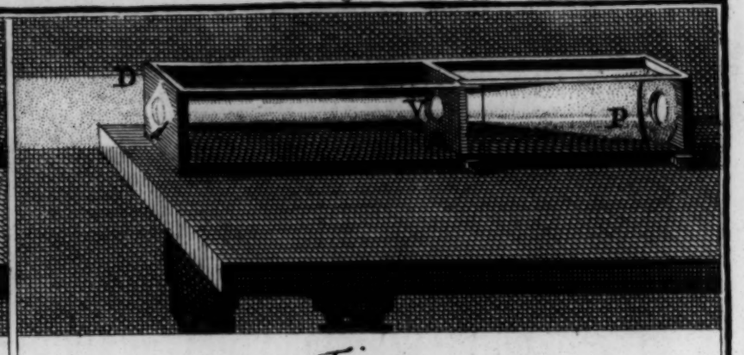


Fig. 7.

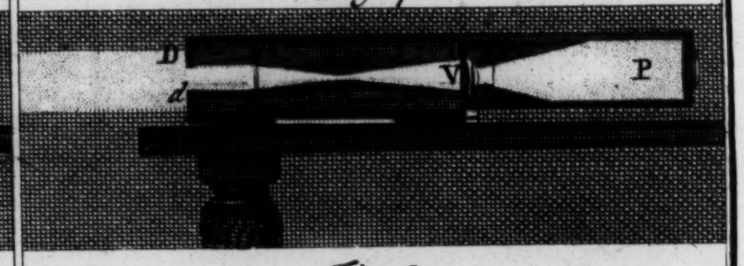


Fig. 8.

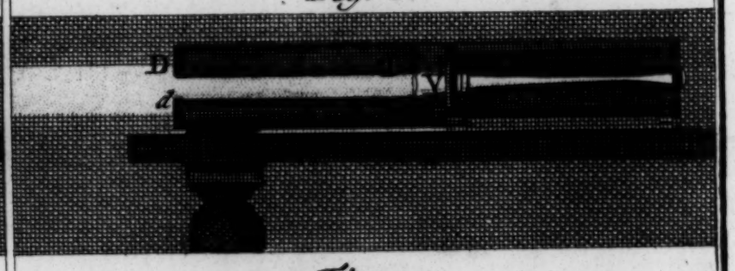


Fig. 9.

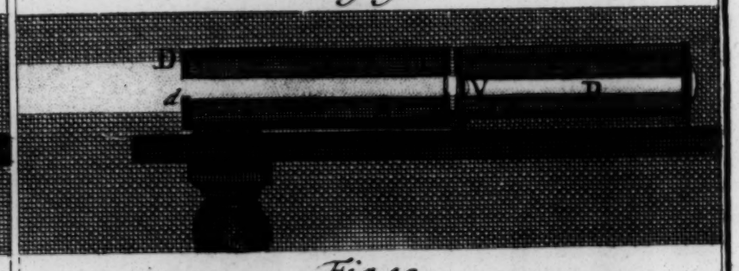
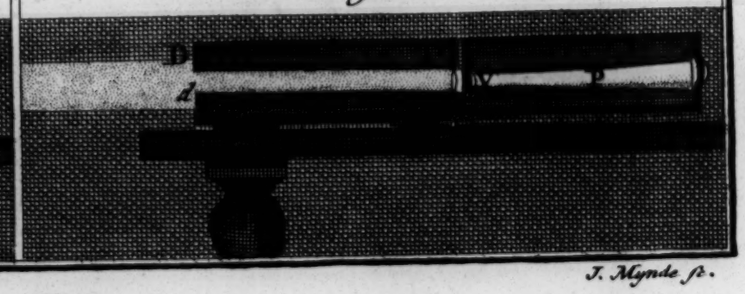


Fig. 10.



J. Mynde sc.

EXPERIMENT 9.

We make uſe of the long Box AB which is open at the Sides *; acroſs this, at right Angles is plac'd the ſmaller Box FE †, in ſuch a Poſition, that the Rays, which enter the greater Box through the Hole *d*, and follow the Direction of it, paſs perpendicularly through the Glaſs Plane of the ſmaller Box, and go out of it through the Glaſs V, whoſe Convexity is outwards. 2962. Pl.93.F.1. * 2755. † 2766.

The Box is fill'd with Water, and the Rays, which are parallel in Air, keep their Direction in the Water *, and paſs into the Air through the ſpherical Surface, whoſe Center is towards the Water; but they converge in the Air. * 2793.

EXPERIMENT 10.

All Things remaining, the Board T, that has the convex Glaſs *, is ſo plac'd, that the diverging Rays may enter into the Water, through the Surface of the Glaſs Plane of the Box E, then the Rays, which remain diverging in the Water †, going into Air, become converging. 2963. Pl.93.F.2. * 2772. † 2885.

If the Radiant comes nearer, the Focus will recede; and laſtly the Rays going out of the Water are parallel. 2964. Pl.93.F.3.

If the Radiant be brought ſtill nearer, ſo that it be in the Surface of the Glaſs Plane, the diverging Rays in their Paſſage into Air remain diverging, but they diverge leſs than in Water. 2965. Pl.93.F.4.

EXPERIMENT 11.

Move the Board T towards the Box E in ſuch Manner, that the converging Rays may go out of the Water, and they will converge more in the Air. 2966. Pl.94.F.1.

There remain to be conſider'd *the Rays, which go out of a more refracting Medium into a leſs refracting one, the concave Surface being towards the leſs refracting Medium. If theſe* Rays *be parallel, they become diverging by Refraction.* 2967.

If they proceed from a radiant Point, they become more diverging. 2968.

And *they ſtill diverge more and more, as the radiant Point is brought nearer.* 2969.

Converging Rays, which tend to the Center of the ſpherical Surface, undergo no Alteration. 2970.

If they converge more or leſs, the imaginary Focus of the incident Rays will always be between the Center of the Surface ſeparating the Mediums, and the Focus of the refracted Rays; which can recede ad infinitum, *ſo as to make the refracted Rays parallel.* 2971.

EXPERIMENT 12.

2972. This Experiment agrees with the ninth, only the Poſition of
Pl. 94. the Box E is alter'd in ſuch Manner, that the Rays may paſs
Fig. 2. through the Glaſs R; then the Rays, which are parallel in the Water, going into the Air diverge.

EXPERIMENT 13.

2973. If by making uſe of the Board T, the Rays diverge in the Wa-
Pl. 94. ter, they will then more diverging, and as the Radiant comes nearer,
Fig. 3. their Diſperſion at the going out is increas'd.

EXPERIMENT 14.

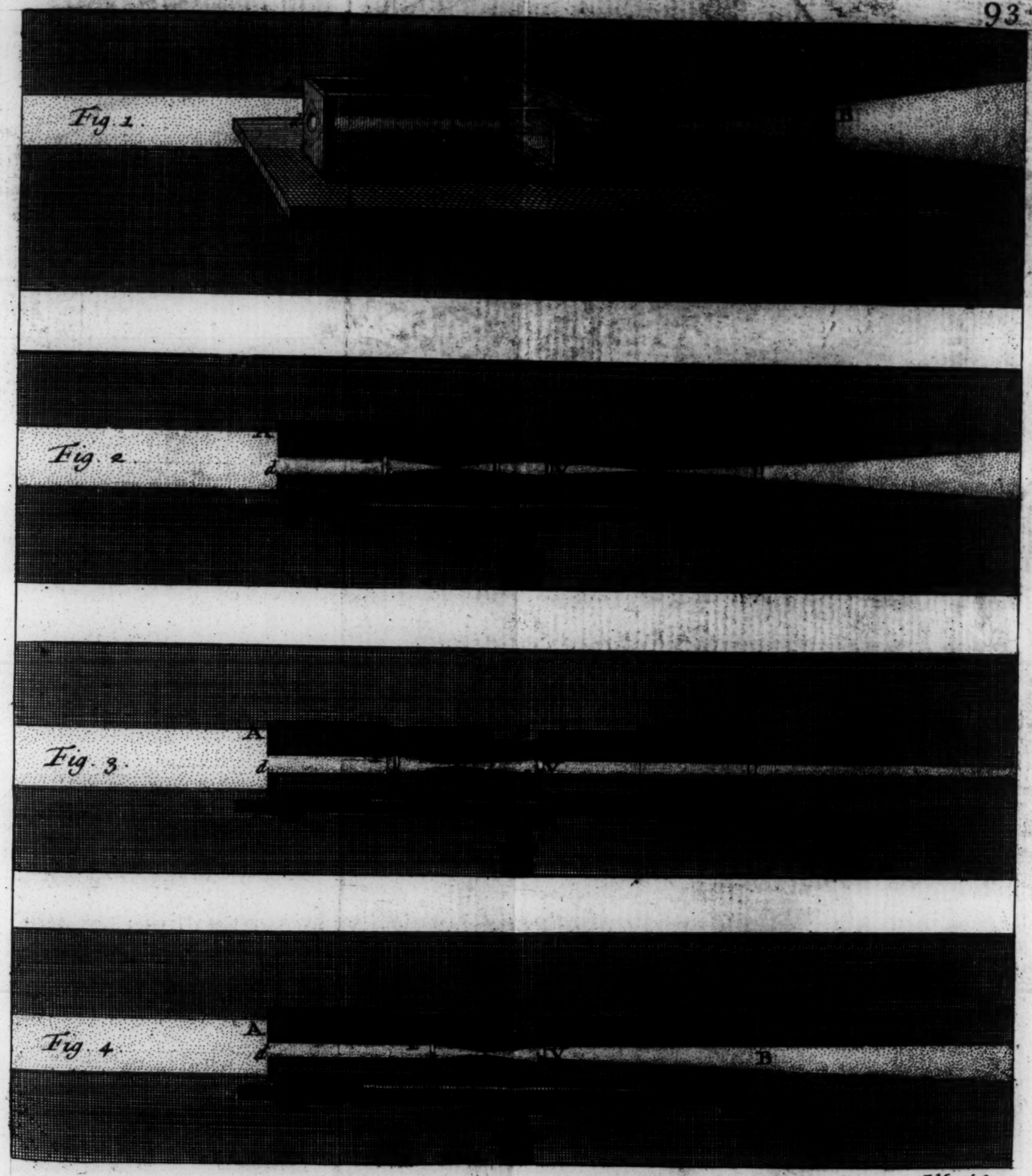
2974. If, the Board being brought near, as in the eleventh Experi-
Pl. 94. ment, the converging Rays fall upon the convex Surface of the
Fig. 4. Glaſs R, in going into the Air they will be left converging.

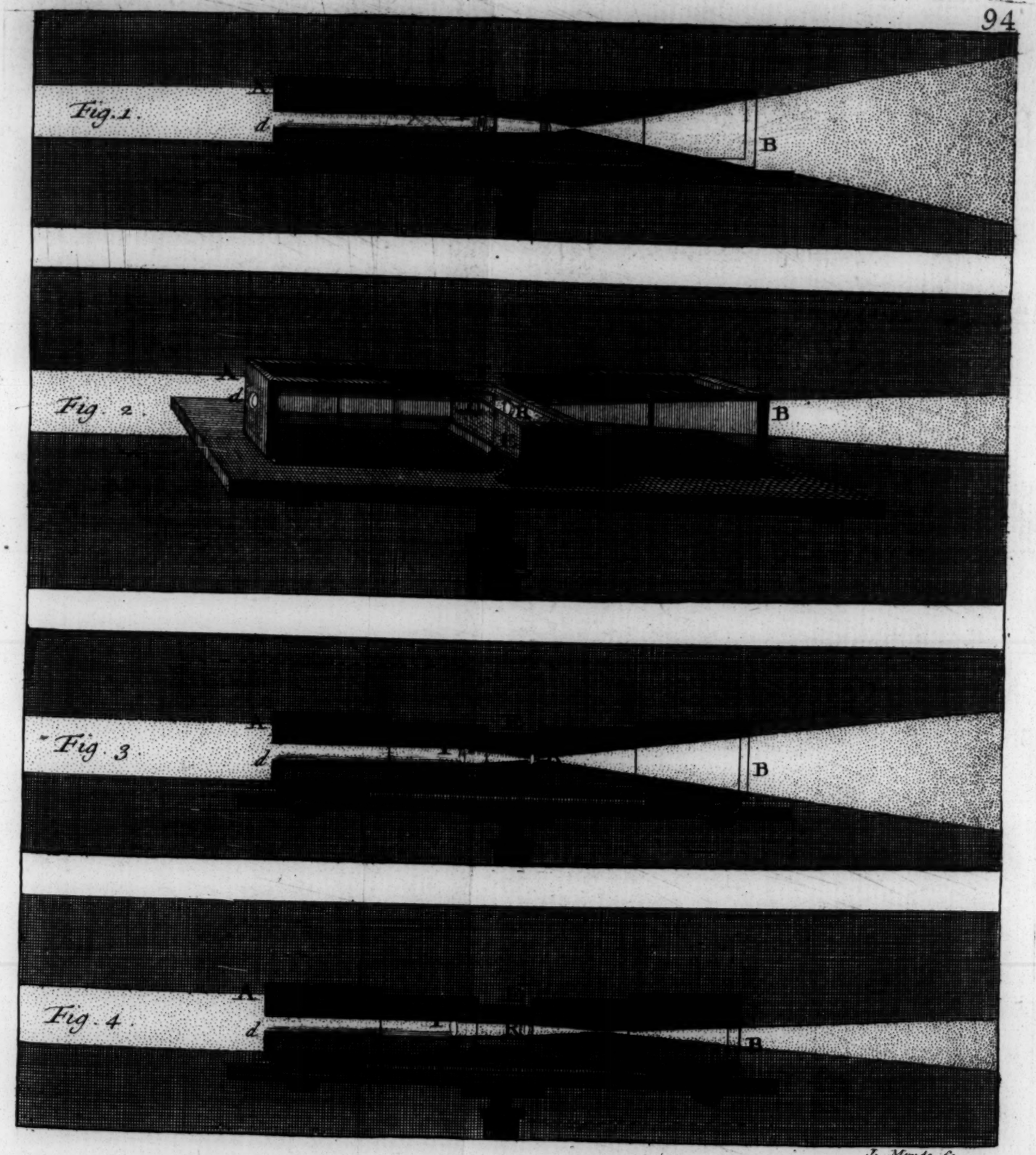
2975. The Board T being brought towards the Box E, the Focus F will recede, and thus this is eaſily remov'd, that the Rays may become parallel.

2976. If then the Board be brought nearer, the Rays will diverge in Air.

2977. If there be many radiant Points, and Rays paſs directly from all of them into a more refracting Medium, through the convex ſpherical Surface on the Side of the leſs refracting Medium, the Diſtance of the Radiants being ſuppos'd ſufficiently great, every one of theſe will have it's Focus * ; but every one of theſe is given, with it's Radiant, in the ſame right Line, which paſſes through the Center of the Sphere, a Portion of which the Surface makes. When all the Radiants are equally diſtant from this Surface, which ſeparates the Mediums, all the Foci are alſo equally remov'd from it on the oppoſite Side. But when all the ſaid Lines paſs through the ſame Point, they make two Pyramids, oppoſite at the Vertex, and ſimilar; wherefore all the Foci are diſpos'd among themſelves, as the radiant Points themſelves, but in an inverted Poſition. If theſe Foci fall upon a white Surface, and the extraneous Light be not too vivid, they will exhibit an inverſe Picture of the radiant Points. But it is required that the radiant Points take up a ſmall Space, otherwiſe the Rays from all, will not be direct together and a little diſpers'd for each of them.

EXPE-


Fig. 1.
Fig. 2.
Fig. 3.
Fig. 4.
A
B
J. Myndoſe.



J. Mynde sc.

EXPERIMENT 15.

All the Points of the Surface of the Flame C, are radiant Points; at the Diſtance of two or three Feet from the Candle is plac'd the Box P *. in ſuch Manner, that the Glaſs, whoſe convex Surface is outwards, may be turn'd to the Candle, and the Light, which enters through it into the Box, may be carried along the Box. 2978. Pl. 96. Fig. 1. * 2671.

The Box muſt be put upon the ſmall Table *, that it's Aperture may be rais'd as high as the Flame. The Light is intercepted by a Paper A B, dy'd with ſome dark Colour, that the Light may enter into the Box only through the Hole *d*, whoſe Diameter is equal to half an Inch. * 2773.

The Box is fill'd with Water, and by making Trial the Poſition of the ſmall Table T, which is made white *, is ſought, that the Foci of the radiant Points may be given upon the Surface of the Table, and all may illuminate one Point; then we ſhall have the Flame of the Candle diſtinctly painted upon this Surface, but inverted. * 2762. 2764.

I ſhall now ſpeak of oblique Rays, a little diſpers'd; but I ſhall only juſt mention what belongs to this Matter, and demonſtrate it in the following Scholiums. 2979.

Let X be the more refracting Medium, Z the leſs refracting Medium; let the Ray A B paſs out of one Medium into another, falling obliquely upon the ſpherical Surface, ſeparating the Mediums, and whoſe Center C is. Through this we draw H C D, parallel to A B, and we determine the refracted Ray B D *; we draw C L perpendicular to this, to which we draw B G parallel, cutting the Line D C at G. Through B is drawn to the Surface, ſeparating the Mediums, a Tangent, which meets the ſame Line D C at H. The Points H and L are join'd by a Line, that cuts B G at I. If a parallel to A B, be drawn through I, this will cut the refracted Ray B D at F, in which Point, all the Rays parallel to A B, and at a ſmall Diſtance from it, meet with this Ray, after Refraction. 2980. Pl. 96. F. 2, 3. * 2919.

If the oblique Rays be diverging, or converging, and a little diſpers'd, we diſcover the Focus, or Point of Diſperſion, by the following Conſtruction. 2981.

Let R be the Radiant Point, or imaginary Focus of the incident Rays; R B one of the incident Rays, or a Continuation of it; B F the ſame Ray refracted *; and it's Continuation B L; Let E be the Focus, or Point of Diſperſion, of parallel Rays proceeding from contrary Parts, in the Direction F B †. 2982. Pl. 96. F. 4, 5. * 2919. † 2980.

The Point G is determin'd by this Proportion, as the Sine of Refraction is to the Sine of Incidence, ſo is E B to E G.

From the Center C, of the Surface ſeparating the Mediums, C L, C D, are drawn perpendicular to the Lines B H, B R; and the Points D and L are join'd by a Line; and R H is drawn parallel to D L. If then it be as R E to E G, ſo is H B to B I, and through I be drawn I F, alſo parallel to D L, F will be the Point ſought.

2983. When R E and E G are directed towards the ſame Part, H B, B F, tend alſo to the ſame Part, as in Fig. 4; if they be oppoſite to the firſt of theſe Lines, H B, B F, are alſo directed towards contrary Parts, as in Fig. 5; which alſo may be thus expreſs'd: That the Point B is to F and H, as E is to G and R.

2984. We ought to refer to this Place, what was ſaid in the foregoing
* 2899. Chapter concerning oblique Rays *; that the Demonſtrations only relate to Rays in the Plane of the Figure.

2985. If the parallel Rays make a Cylinder, whoſe Section through the
Pl. 96. Axis is between A B, *a b*, the refracted Rays paſs through the ſmall
Fig. 2. Line, perpendicular to the Plane of the Figure at F; and afterwards paſs through the ſmall Line D *d*. If we conceive a Plane between F and D, againſt which the Rays run directly, theſe will make there a rectangular Spot, which is had for the Focus, or
* 2903. Point of Diſperſion, when it is ſquare *.

2986. The ſame Things obtain in diverging and converging Rays; all
Plate 96. the Rays paſs through the ſmall Line, perpendicular to the Plane of
Fig. 4, 5. the Figure at F; and in this Plane the ſame Rays paſs through a ſmall Portion of the Line, which wou'd paſs through R and C, and in which this ſmall Portion wou'd be determin'd by the Interſection of the Lines B F, *b* F, continued if Occaſion requir'd.

But the Places where the Spots are ſquare are determin'd by Conſtructions like thoſe, which were deliver'd in the laſt Chapter, which I ſhou'd explain more diſtinctly, if this Determination were of any uſe in explaining Phenomena.

But we ſpoke of determining the Point F, that it might ap-
* 2961. pear, that what was demonſtrated in another Caſe *, obtains here
2987. alſo, that *there is no Focus, or Point of Diſperſion of oblique, diverging, or converging Rays, how little ſoever they are diſpers'd, if the Mediums be ſeparated by a ſpherical Surface*; which follows from what was ſaid of the Spot, or ſmall Space, through which the Rays between F and D paſs.

All

All Alterations in Light, ſpoken of in this Chapter, *are the more ſenſible, as the Surface, ſeparating the Mediums*, is more curve, that *is, a Portion of a leſs Sphere.* 2988.

SCHOLIUM I.

A Demonſtration of the Rule, deliver'd in N. 2930, *concerning the Determination of the Refraction of direct Rays.*

LET us ſuppoſe the Ray RB, or *r*B, to be refracted along BF, or along the Continuation of it B*f*; we muſt demonſtrate that the Refraction was well determin'd, thoſe things being ſuppoſed, which were explain'd in N. 2931. 2989. Pl. 95.. F. 5, 6, 7, 8.

The Angle of Incidence is RBC, or it's Complement to two right ones. The Angle of Refraction is CBF, or it's Complement to two Right ones. If the Ray EB be an incident Ray, B*a* will be refracted *; the Angle of Incidence will be EBC, or it's Complement to two Right ones; and the Angle of Refraction *a*BC; or it's Complement to two Right ones. All thoſe Angles (or at leaſt their Complements, which are then to be uſed) are ſmall, and therefore they are as their Sines; therefore, as there is a conſtant Ratio between the Sines of Incidence and Refraction, in this Caſe alſo, that is, *when the Angles are ſmall, there is given that* ſame *conſtant Ratio of Refraction between the Difference of the Angles of Incidence and the Difference of the Angles of Refraction* *; that is, there is this Ratio between the Angles RBE, or *r*BE, and *a*BF, or *a*B*f* = BFV †, as alſo between the Sines of them; which therefore are as EC to EB *. But theſe Sines are in a Ratio compounded of the Sine of the Angle RBE to the Sine of the Angle BRV, and the Ratio of the Sine of this laſt to the Sine of the Angle BFV. * 2789. * 16. 17. El. 5. † 29. El. 1. * 2919.

The firſt Ratio is that which is between RE and EB *. The ſecond Ratio is between FB and RB, or VF and RV, by reaſon of the ſmall Arch BD: therefore * 2923. 2924.

EC : EB : : RE × VF : EB × RV.

EB × RE × FV = EC × EB × RV, or RE × FV = EC × RV.

And RE : EC : : RV : VF. Which was to be demonſtrated.

SCHOLIUM II.

The Demonſtration concerning the Refraction of parallel oblique Rays, explain'd in N. 2980.

LET AB, *a b*, be parallel Rays; their refracted Rays BD, *b d*; we alſo ſuppoſe what elſe was mention'd in N. 2980. 2990. Pl. 96. F. 2.

From the Refraction it follows, *b d* : *d*C : : BD : DC *; * 2919.

By Altern. and Diviſ. and by Altern. again, *d m* + *a b* : D*d* : : BD : DC.

The Triangles D*d m* and DBG are ſimilar; and

D*d* : : *d m* : DG : BD.

Therefore by equal Perturb. $dm + cb : dm :: DG : DC$;

2991. By Divif. $eb : dm :: DG - DC = CG : DC$.

But the Point F is ſought, in which is given the Interſection of the Rays BD, *bd*.

By Reaſon of the ſimilar Triangles BF*e*, DF*m*,

2992. $Be : Dm :: BF : FD$.

The Ratio between B*e* and D*m* is made up of the three Ratios of B*e* to *eb*, *eb* to *dm*, and laſtly *dm* to D*m*; which three Ratios we determine. GN being drawn parallel to BD, the Triangles B*eb* and BGN are ſimilar, and

$Be : eb :: BG : GN$.

* 2991. $eb : dm :: CG : DC$ * $:: BL : LD$; by reaſon of the Parallels BG, LC.

$dm : Dm :: DB : BG$; by reaſon of the ſimilar Triangles D*dm*, BDG.

Therefore B*e* is to D*m*, as the Product of the Antecedents BG × BL × DB, to the Product of the Conſequents GN × LD × BG, in which

* 2992. Ratio alſo BF is to FD *.

But $GN \times LD = BD \times GO$; for, by reaſon of the Parallels DB, GN,

$BD : GN :: DL : GO$.

Therefore $BF : FD :: BG \times BL \times DB : BD \times GO \times BG :: BL : GO$; in which Ratio alſo is BI to IG, by reaſon of the ſimilar Triangles BLI, IGO.

Therefore a Line drawn through I parallel to GD determines the Point F; for then $BF : FD :: BI : IG$.

2993. If we conceive the Plane of the Figure to turn about the fixed Line DCH, the Rays AB, *ab*, turn about in ſuch manner, as to make Cylinders, which have the common Axis DH; all the Rays parallel to this Axis, which are contain'd between the Surfaces of theſe Cylinders, make by their mutual Interſections a Circle, which the Point F deſcribes, in the ſaid Revolution. The Rays a little diſperſed, which we ſpoke of in N. 2980, are contain'd between the ſaid Surfaces of the Cylinders; therefore theſe, by mutual Interſections, make a ſmall Portion of the ſaid Circle; that is, they paſs through the ſmall Line, perpendicular to the

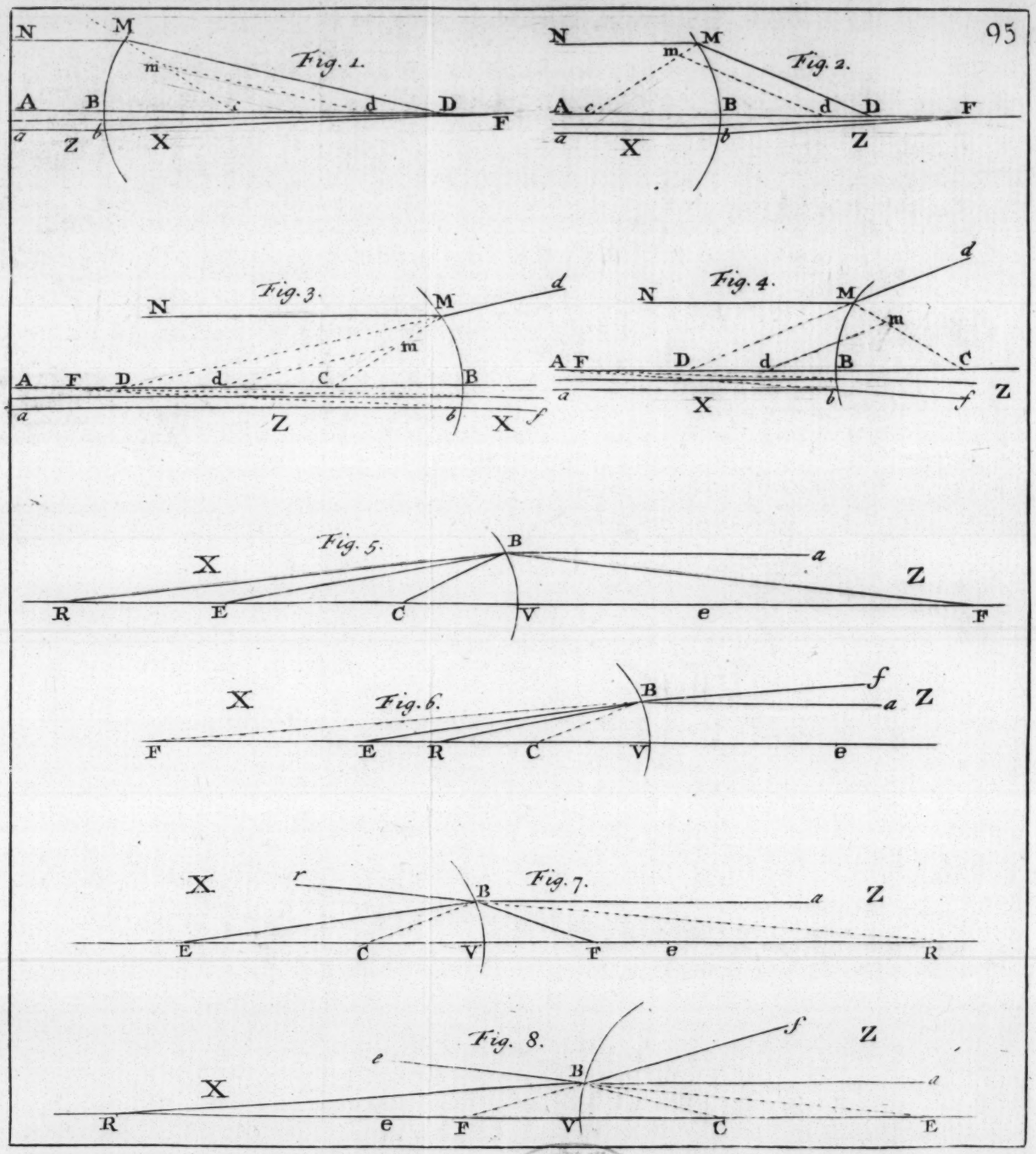
* 2985. Plane of the Figure at F, as has been ſaid *.

SCHOLIUM III.

Of the Refraction of oblique Rays, diverging, or converging, mention'd in N. 2982.

2994. Pl. 96. F. 4. WHAT has been explain'd in N. 2982. being ſuppoſed, we conceive the Ray R*b* which is refracted along *b*F, meeting with the refracted Ray BF at F; we muſt demonſtrate that the Point F was well determined.

With


Fig. 1.
N
M
m
A
B
d
D
F
a
Z
b
X
Fig. 2.
N
M
m
A
c
B
d
D
F
a
X
b
Z
Fig. 3.
N
M
d
m
A
F
D
d
C
B
a
Z
b
X
f
Fig. 4.
N
M
d
m
A
F
D
d
B
C
a
X
b
f
Z
Fig. 5.
X
B
a
Z
R
E
C
V
e
F
Fig. 6.
X
B
f
a
Z
F
E
R
C
V
e
Fig. 7.
X
r
B
a
Z
E
C
V
F
e
R
Fig. 8.
f
Z
e
B
X
a
R
e
F
V
C
E

With the Center R, through B, is deſcrib'd the Arch B*m*; with the Center F, through *b*, is deſcrib'd the Arch *bn*; with the Center B, through the Points L, D, and E, are deſcrib'd the Arches L*l*, D*d*, E*e*.

The Triangles C B L, B*bn*, are ſimilar; for they are rectangular, and moreover the Angles *b* B*n* and B C L are equal; becauſe C B L is the complement of each to a right Angle; which follows with regard to B C L from the Property of Triangles *; and with regard to *b* B*n* from this, that the three Angles *b* B*n*, *b* B C, C B L, are equal to two right ones †, and the middle one of theſe is a right one. * 32. El. 1. † 13. El. 1.

After the ſame manner we prove that the right-angled Triangles B*bm*, B C D, whoſe Angles *b* B*m*, C B D are equal, are ſimilar; becauſe *m* B C is the Complement of each to a Right Angle. Therefore,

bn : B*b* : : B L, B C.
B*b* : B*m* : : B C, B D;

And by Equality, *bn*, B*m* : : B L, B D : : B H, B R. 2995.

But the Ratio of *bn* to B*m*, is made up of the Ratios of *bn* to L*l*, L*l* to D*d*, D*d* to E*e*, E*e* to B*m*.

We find all the Ratios, 2996.

By Reaſon of the ſimilar Triangles F*ba*, B L*l*,
bn, L*l* : : F B, B L : : I B, B D.

For the incident Ray R B, and the refracted one B F, the Sine of Refraction is C L, and the Sine of Incidence C D; for *a* B and B*e*, the ſame Sines are C*l*, C*d*; therefore, by reaſon of the conſtant Ratio between theſe Sines *, * 2809.

L*l*, D*d* : : C L, C D † : : B E, E G. † 19. El. 5.

By Reaſon of the ſimilar Triangles B D*d*, B E*e* and R E*e*, R B*m*,

D*d*, E*e* : : B D, B E;
E*e*, B*m* : : R E, R B.

Therefore the Ratio of *bn* to B*m*, that is, of B H to B R *, is made up of theſe four Ratios, of I B to B D, B E to E G, B D to B E, and R E to R B. * 2995.

The Ratio compounded of the Ratios of I B to B D, B D to B E, B E to E G, is that which is between I B and E G; which therefore only muſt be join'd with the Ratio of R E to R B; and we have

R E × I B, R B × E G : : B H, B R : : B H × B I, B R × B I *. * 1. El. 6.

The Antecedents of the firſt and laſt of theſe Ratios being divided by I B, and the Conſequents by B R, there is given

R E, E G : : B H, B I.

Whence it appears that in the Conſtruction N. 2982, the Point I, and therefore F, was well determin'd.

If, in order to make appear, what was explain'd in N. 2986, we would apply to theſe Caſes, what was demonſtrated in Numbers 2907 and 2993, we ought to conceive the Plane of the Figure to revolve about the fix'd Line R C, and then, what was ſaid in theſe Numbers of the Rays A B, A*b*, will be to be applied to the Rays R B, R*b*. 2997.

CHAP. IX.

Of the Motion of Light through a more refracting Medium. Where we ſhall ſpeak of the Properties of Lenſes.

2998. THE uſe of Glaſſes is common; Glaſs is denſer than Air,
* 2830. and more refracting according to the Ratio of the Denſity *; and the Rays coming out of the Air into Glaſs, paſs though it into the Air again. Light undergoes different Changes in it's Paſſage through Glaſſes, according to the various Surfaces that terminate them. In order to determine which, the Glaſſes or any Mediums encompaſs'd with a leſs refracting Medium, terminated with different Surfaces, muſt be examin'd. *There are ſix Claſſes of Glaſſes ariſing from the ſole Conſideration of plane and ſpherical Surfaces.*

2999. 1. The Medium may be plane on both Sides. 2. It may be plane on one Side and convex on the other. 3. It may be convex on both Sides. 4. It may be plane on one Side, and concave on the other. 5. It may be concave on both Sides. 6. It may be concave on one Side, and convex on the other.

DEFINITION 1.

3000. *If a Glaſs* be us'd, and it *be not very thick, ſuch a Glaſs as is mention'd in the five laſt Claſſes, is call'd a Glaſs Lenſe.*

3001. In the ſecond and third Caſe, a Lenſe is ſaid to be convex; and if theſe two Caſes are to be diſtinguiſh'd, in the ſecond it is call'd a Plano-convex Lenſe. And ſo in the fourth Caſe it is ſaid to be Plano-concave; though both theſe Caſes and the fifth are generally reckon'd as concave Lenſes. But a concave convex Lenſe, is reckon'd amongſt concave or convex Lenſes, according as the one or the other Surface predominates, in which laſt Caſe the Lens is call'd a Meniſcus. But that Surface is ſaid to predominate which is moſt curve, that is, which is a Portion of a leſs Sphere.

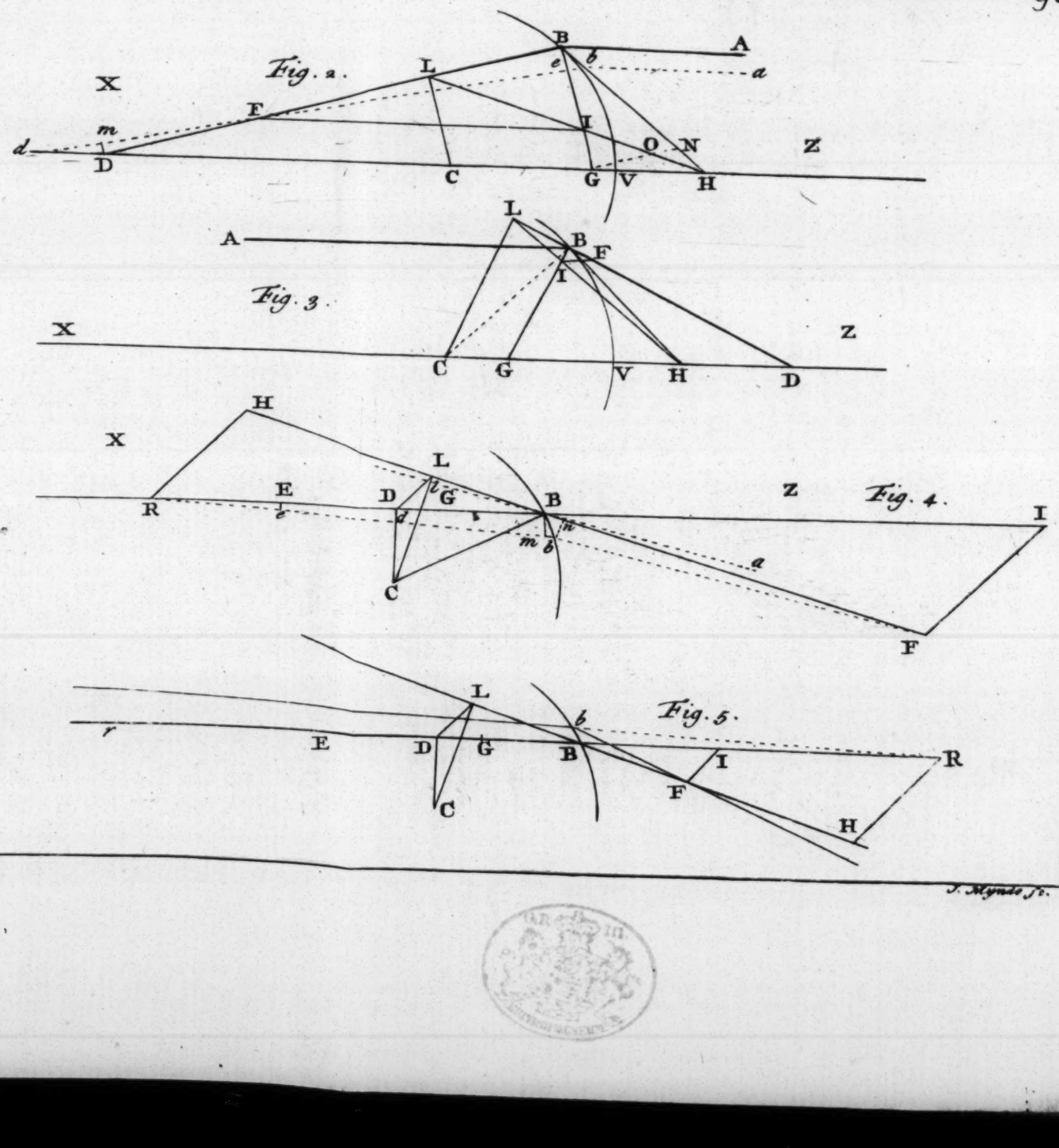
DEFINITION 2.

3002. *In any Lenſe or Medium terminated, as has been already ſaid, the right Line which is perpendicular to both the Surfaces is call'd the Axis.*

When



Fig. 1.



J. Mynde fc.

When both theſe Surfaces are ſpherical, the Axis paſſes through both their Centers; but if one of them be a Plane, it falls perpendicular upon that, and goes through the Center of the other. 3003.

Regular Lenſes are orbicular, and the Axis paſſes through the Center of the Lenſe, in which Caſe it is ſaid to be well center'd. 3004.

In the Paſſage of Light through a Medium, terminated by two plane Surfaces, *the Direction of the Rays is not chang'd* *, which is the Caſe *in plane Glaſſes.* 3005. * 2792.

In demonſtrating what relates to the Paſſage of Light through Lenſes, we ſhall only conſider Rays a little diſpers'd, as before, and indeed principally thoſe that are direct. But thoſe are ſuch, among which there is one, that coincides with the Axis of the Lenſe *. 3006. * 2878 3002.

It is the Nature of all Sorts of convex Lenſes, that the Rays in their Paſſage through them are bent towards one another; ſo much the more as the Convexity is greater: But *of concave ones, that the Rays are deflected from one another, according as the Concavity is greater.* 3007. 3008.

For the Direction of the Rays through a plane Glaſs is not alter'd *; but upon inflecting one or both the Surfaces, the Rays will have another Direction: They are more bent towards the Axis of the Lenſe, becauſe of the Convexity of the Surface of the Glaſs; and by making the Surface concave, they are deflected from the Axis; as is evident in every Caſe, by comparing the Inflection in the plane Surface, perpendicular to the Axis of the Glaſs, with the Inflection in the ſpherical Surface. And the Difference of their Inflections, that is, the Change of the Direction of the Rays, increaſes with the Diſtance from the Axis. Whence we deduce the following Properties of Lenſes. 3009. * 3005.

That *parallel Rays in paſſing through a convex Lenſe, meet in the Focus.* 3010.

That *diverging Rays either diverge leſs, or run parallel, or elſe converge; in which Caſe as the Radiant Point goes farther off, the Focus comes nearer, and contrariwiſe:* And this is the Caſe when the Radiant Point is farther diſtant from the Lenſe than the Focus of parallel Rays. 3011.

Laſtly, That *converging Rays converge more when the Light emerges out of the Lenſe.* 3012.

Experiment 1.

In this, and the following Experiments, we make uſe of the long Box A B *, which has been often us'd before; the Sides of it are clos'd. We direct the Ray horizontally, as in many of the foregoing 3013. Pl. 97. F. 1. * 2755.

foregoing Experiments; according to the Direction of this the Box is plac'd, into which the Light enters through the Hole *d*. The parallel Rays are tranſmitted through the convex Lenſe, which is
* 2772. in the Board T *, they converge, and meet at R.

In this, and the following Experiments, the Rays are made
* 2801. ſenſible, by making uſe of a white Powder *, as has been often ſaid.

3014. We have already often us'd theſe converging Rays; after their Interſection at R they are diſpers'd, and R is the radiant Point, which alſo has been often made uſe of in the Experiments; but we have now explain'd the Cauſe of this Effect in the Paſſage through the Lenſe.

Experiment 2.

3015. All Things remaining the ſame, we put a ſecond Board S like
Pl.97.F.1. T, which alſo has a convex Glaſs, into the Box A B; the diverging Rays, proceeding from R, will become converging, and meet at the Focus F, if the Diſtance R S be great enough.

3016. If this Diſtance be diminiſh'd, the Focus F will recede; and
Pl.97.F.2. this may be remov'd in ſuch Manner, that the Rays going out of the Lenſe S will be parallel.

3017. If the ſaid Diſtance R S be then diminiſh'd more, the Rays that
Pl.97.F.3. go out will diverge, but they will diverge leſs than incident Rays.

Experiment 3.

3018. Other Things remaining, the Board T muſt be mov'd towards
Pl.97.F.4. the other S in ſuch Manner, that the Rays may fall upon the Lenſe of this Board converging; and when they go out they will converge more.

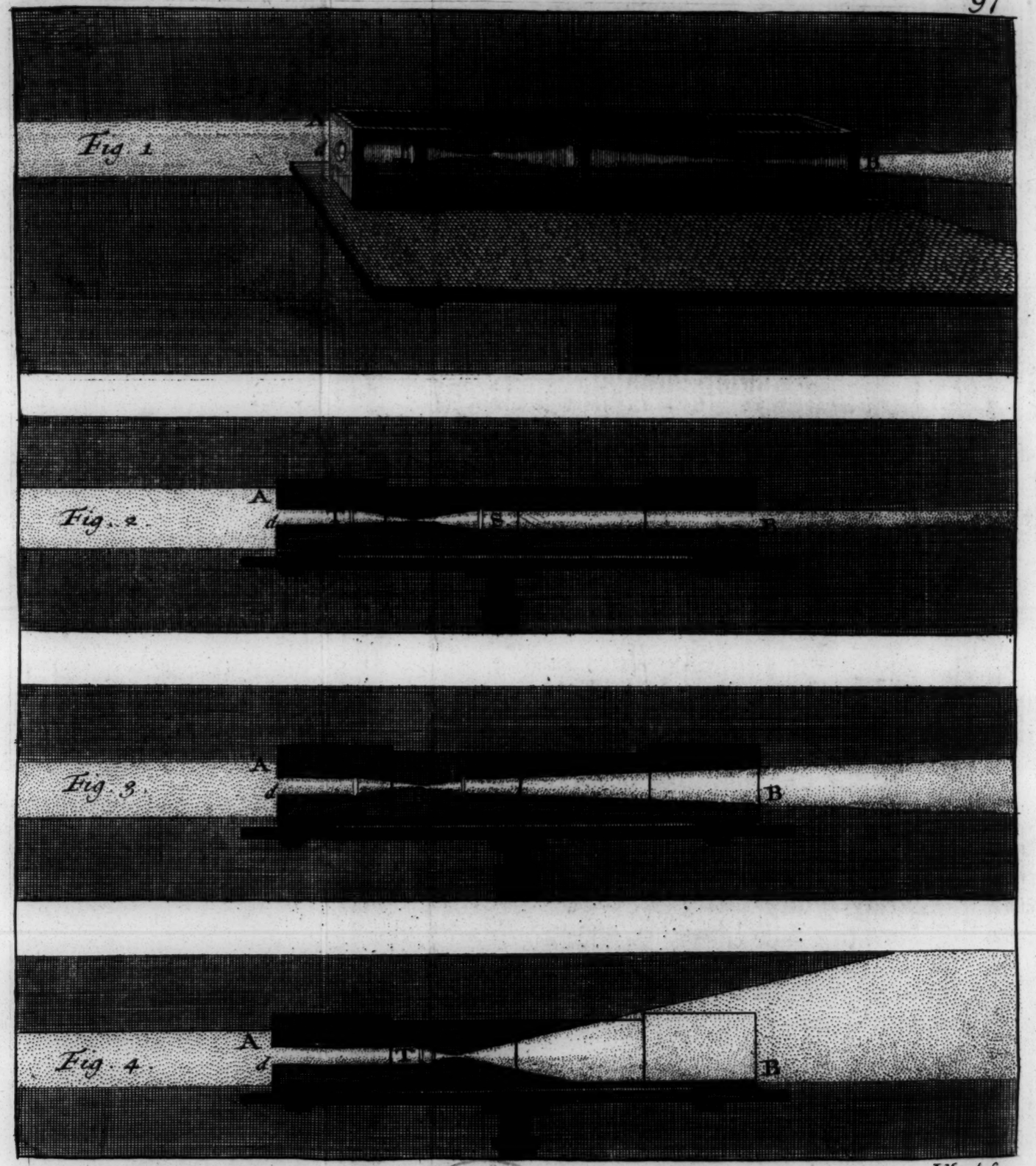
3019. We alſo deduce the Properties of concave Lenſes from a general
* 3008. Propoſition *.

3020. *Parallel Rays become diverging by paſſing through a concave Lenſe.*

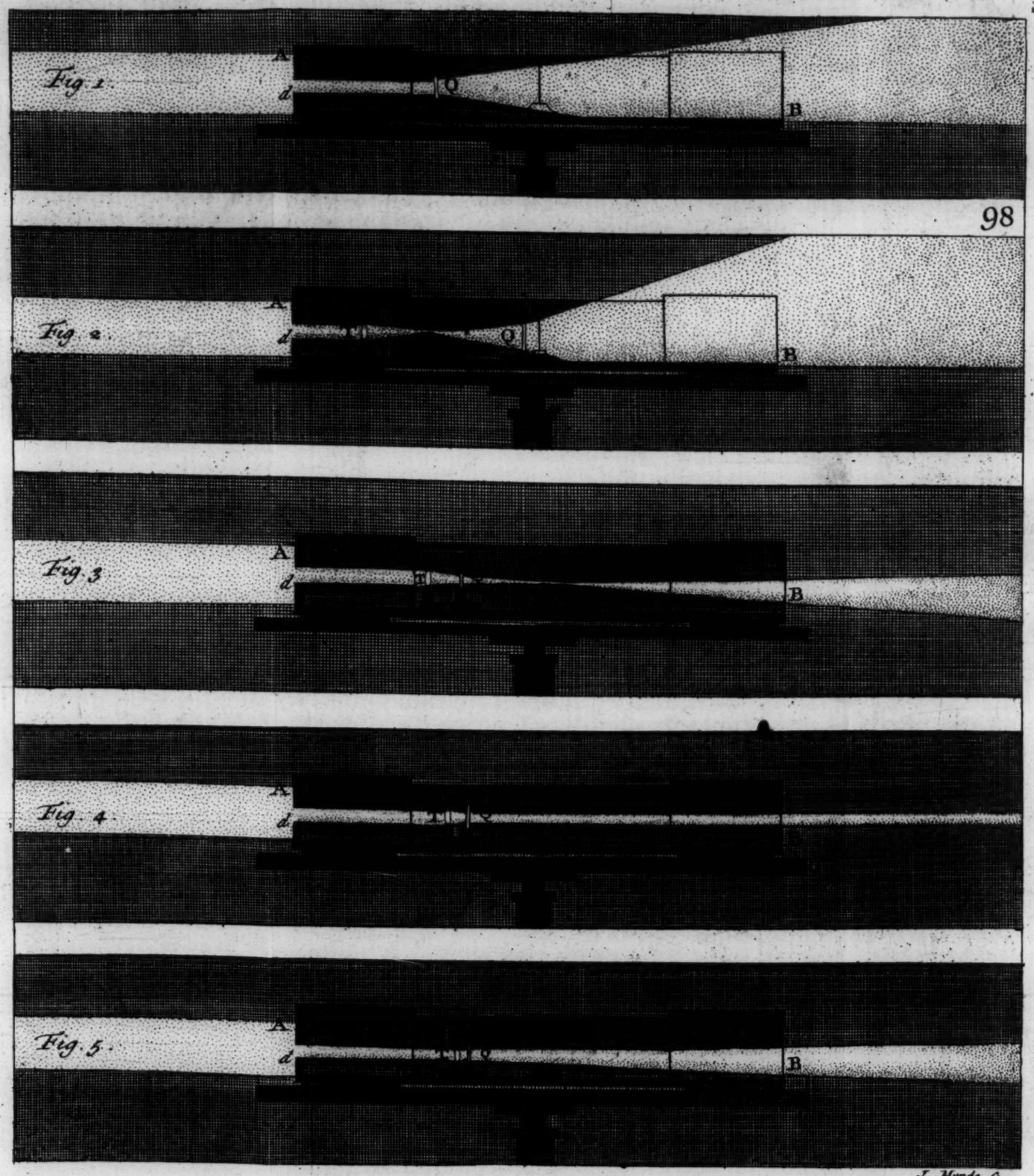
3021. *Diverging Rays diverge the more.*

3022. *Converging Rays ſometimes converge the more; if, in this Caſe, the converging of the incident Rays be diminiſh'd theſe may be directed, ſo that when they go out they will be parallel; if then the incident Rays become ſtill leſs converging, at their going out they will be diſpers'd.*

Expe-



J. Mynde sc.



J. Mynde sc.

EXPERIMENT 4.

This Experiment is made like the firſt *; but inſtead of the Board T we uſe another Q, that has a concave Lenſe. Parallel Rays that paſs through it, go out diverging. 3023. Pl.98.F.1. * 3013.

EXPERIMENT 5.

All Things remaining, we make uſe of the Board T alſo, which we us'd in the firſt Experiment mention'd *; by Means of this we make the radiant Point R, from which Rays diverging fall on the concave Lenſe of the Board Q, and go out more diverging. 3024. Pl.98.F.2. * 3013.

EXPERIMENT 6.

The ſame Things remaining, bring the Board T towards the Board Q, in ſuch Manner, that converging Rays may fall upon the concave Lenſe, and when they emerge they will converge leſs. 3025. Pl.98.F.3.

The Board T may be brought ſo near, that the Rays emerging from the concave Lenſe will be parallel. 3026. Pl.98.F.4.

The Board T being brought ſtill nearer, the Rays going out of the ſecond Lenſe will diverge. 3027. Pl.88.F.5.

We have demonſtrated the general Properties of Lenſes, I ſhall now ſpeak of determining the Refractions themſelves nicely, but I ſhall only mention the Propoſitions, and give the Demonſtrations of them in the following Scholiums. 3028.

A Lenſe being given, that is terminated by two ſpherical Surfaces, the Point of Concourſe, or Diſperſion of parallel Rays, is ſought. 3029.

The Rectangle made of the Semidiameters of the Surfaces is multiplied by the Number, which expreſſes the Sine of Refraction in Glaſs, and the Product is divided by the Difference of the Sines in Air and Glaſs. This Quotient being divided by the Diſtance between the Centers, that is, by the Sum of the Semidiameters, when both Surfaces are concave, or convex, and by the Difference, when one is concave and the other convex, there will be given in the Quotient *the Diſtance of the Point ſought from the Lenſe*; which *is the ſame from whatever Part the Rays proceed.* 3030. 3031.

The Ratio of Refraction out of Air into Glaſs is that, which is between 17 and 11 *, nearly as 3 to 2. Therefore we muſt multiply by 11, and divide by 6; or only multiply by 2. 3032. * 2811.

If one Surface be plane, the Semidiameter becomes infinite, and is had as equal to the Sum or Difference of the Semidiameters; in this Caſe the Semidiameter of the ſpherical Surface is multiplied 3033.

by 11, and divided by 6; or is doubled, the more accurated Determination being neglected.

3034. The Points, which we diſcover by theſe Computations, are the
* 3007. Points of Concourſe, if we conſider convex Lenſes *, and the
† 3008. Points of Diſperſion if they be concave †.

If direct Rays, either diverging or converging, fall upon a Lenſe, we diſcover the Motion after the Paſſage by this Proportion.

3035. *As the Diſtance, between the Point, to which the incident Rays come, and the Point of the parallel Rays, proceeding from a contrary Part, is to the Diſtance between the firſt of theſe Points and the Glaſs itſelf, ſo is this laſt Diſtance to the Diſtance between the Point of the incident Rays, and the Point ſought of the refracted Rays.*

3036. With regard to which Proportion we obſerve, that the Point of the refracted Rays is always with reſpect to the Point of the incident ones at the ſame Part, at which the ſaid Point of the parallel Rays is with reſpect to this.

3037. Let R be the Radiant, or imaginary Focus of the incident Rays;
Plate 100. E the Focus, or Point of Diſperſion, of parallel Rays coming from
F. 1, 3, 4. a contrary Part; F the Focus, or Point of Diſperſion, of the refracted Rays; according to the Rule R E, R V, R F, are in continued Proportion.

* 3030. In the contrary Motion, V *e* being taken equal to V E *, F *e*, F V, F R, will be the Proportionals.

What has been ſaid regards direct Rays, one of which coincides with the Axis of the Lenſe, which in going through keeps it's Di-
3038. rection. But this is not a peculiar Property of this Ray; *all the Rays that paſs through the Center of the Lenſe keep their Direction* alſo.

3039. Let V be the middle Point of the Lenſe; A B it's Axis; C D
Pl. 99. F. 1. an incident Ray, which, being refracted along D E, paſſes through V; this, if the Lenſe be equally convex, or concave, both Ways, will go out of the Glaſs at E, where the Surface is parallel to the Surface at D, and the refracted Ray E F will be parallel to the
* 2792. incident Ray C D *; that is, it will go in the ſame Direction. If the Lenſe be thin, the Lines C D and E F make the ſame right Line to Senſe.

3040. If the Lenſe be unequally convex, or concave, the Point of Interſection of the Rays, not bent, is not in the Middle of the Thickneſs of the Glaſs. When one Surface of the Glaſs is plane, this Point is in the Interſection of the Axis of the Glaſs and the ſpherical Surface. In a Lenſe one of whoſe Surfaces is concave,

and the other convex, the Point, we are ſpeaking of, is without the Lenſe, on the Side of that Surface, which is a Portion of a ſmaller Sphere.

If ſeveral incident and refracted Rays paſs through this ſame Point, 3041.
they make two ſimilar Pyramids, which have a common Vertex, in that ſame Point.

If the incident Rays be oblique, parallel, or belonging to a Point, 3042.
although they be *a little diſpers'd*, when they are *refracted, they don't belong to one Point*; by Reaſon of the double Irregularity in the Refraction, the firſt at the going in, the ſecond at the going out *. * 2987.

But *if the Rays become ſomewhat oblique, and paſs through the* 3043.
Center of the Lenſe, the Refraction does not differ much from the Refraction of direct Rays.

Let R be the radiant Point in the Axis of the Lenſe, remov'd 3044.
from the convex Glaſs U in ſuch Manner, that it may have the Pl.99.F.2.
Focus F; let *r* be the other radiant Point, and *r U f* the Ray, whoſe Direction is not alter'd *, the other Rays, which are a little * 3038.
diſpers'd, meet with this Ray, at the Diſtance *V f*, which, if *r* U be equal to R U, does not differ much from U F.

If we conſider the Thing mathematically, U P exceeds U*f*, and the direct Concourſe is more perfect, but the Differences are ſmall, as we find, if we attend to what is demonſtrated concerning oblique Rays in the foregoing Chapter.

If beſides theſe there are given more radiant Points alſo, from 3045.
which alſo the Rays that are a little oblique fall upon the Glaſs, the right Lines, which tend from all the radiant Points to their Focus's make two oppoſite ſimilar Pyramids *, one of which has * 3041.
for it's Baſe the radiant Points, the other the Focus's of them.

If theſe Focus's fall upon a white Plane, each of the radiant 3046.
Points illuminates a correſpondent Point upon the Plane; and all the Focus's together give an inverſe Figure of the radiant Points, ſuch as has been before repreſented *. * 2977.

Experiment 7.

We put the Board with it's Lenſe * upon a moveable Table †; 3047.
we raiſe the Table, that the Lenſe may be at the ſame Height * 2770.
with the Flame of a Candle put upon another Table, at any Diſ- † 2774.
tance whatſoever. We turn the Lenſe, that it's Axis may paſs through the Flame of the Candle; the Picture of the Candle will be repreſented inverted upon Paper, placed at a juſt Diſtance, and parallel to the Lenſe.

3048. This Picture is the moſt perfect of all, when the Rays paſs through the middle of the Lenſe, but if the Lenſe being cover'd, the Rays be tranſmitted through the Aperture, a little remote from the Axis of the Lenſe, the Figure of the Flame will be diſtinct enough, by Reaſon of the ſmall Obliquity of the Rays proceeding from the Candle. The Place of the Picture will be the ſame alſo; for the Rays, which, in this Caſe, make the Focus, wou'd meet with the Ray, that is not bent, if this were not intercepted.

Experiment 8.

3049. Things remaining as in the laſt Experiment, let the Lenſe be covered with black Paper; three or four ſmall Holes being left in the Paper, whoſe Diameters are equal to a Quarter of an Inch; the Picture of the Flame is repreſented on a white Plane in the ſame Manner as in the foregoing Experiment; but, the Poſition of the Plane being alter'd, we have ſo many imperfect Repreſentations of the Flame, as there are Holes, through which the Light paſſes.

3050. As by Means of a convex Lenſe we repreſented the Flame of a Candle, ſo we may repreſent the Body of the Sun, by placing a Lenſe in ſuch Manner, that it's Axis may paſs through the Sun; in this Caſe the Sun's Rays which paſs through the whole Lenſe, are

3051. reduc'd into *a* ſmall Space, in which Caſe the *convex Lenſe is a burning Glaſs.*

Experiment 9.

3052. Let there be a convex Lenſe as U, whoſe Diameter is ſix Inches;
Plate 100. let this be directed in ſuch Manner, that one of the Sun's Rays
Fig. 4. may coincide with the Axis of the Lenſe; if this collects parallel Rays, ſuch as all are to Senſe, which proceed from all the Points of the Sun, at the Diſtance of three Feet, and a Body that is eaſily

3053. ſet on Fire be placed there, as Wood, upon which the Image of the Sun falls, it will take Fire. But as this Image is not very ſmall, not only by Reaſon of the Magnitude of the Sun itſelf, but alſo

* 2895. becauſe the Picture is imperfect *, by Means of a ſecond convex

† 3012. Lenſe L, through which the Rays become more converging †, the Space is narrow'd in which the Combuſtion is made.

This ſecond Lenſe is chiefly neceſſary, when the firſt Lenſe is large, of the Diameter of two or three Feet. By theſe the Violence of the Fire is greatly increas'd.

SCHO-

SCHOLIUM.

Demonſtrations of the Rules, concerning Refractions through Glaſſes, delivered in Numbers 3030, *and* 3035.

LET there be a Lenſe U terminated by two ſpherical Surfaces; let C and D be the Centers of the Surfaces. Let us ſuppoſe a Ray to be given, which coincides with the Axis of the Lenſe, and paſſes along EUR in a right Line; let AB be a Ray at a little Diſtance from it, and parallel to it, the Point F is ſought, in which ſuch Rays wou'd meet, after their paſſing through the Glaſs, with the Axis, or wou'd meet being continued backwards. 3054. Pl. 99. F. 3, 4, 5.

Let R be the Point, to which theſe Rays come, whilſt they penetrate into the Glaſs, that is, R is the imaginary Focus, or Point of Diſperſion, of the Rays in the Glaſs after the firſt Refraction.

Let E be the Point to which parallel Rays would come, that proceed from a contrary Part, if they ſhould penetrate into the Glaſs, through the oppoſite Surface, and continue their Motion in it. Moreover let the Ratio which is given between the Sine of Incidence in the Air and the Sine of Refraction in Glaſs, be that which is given between *m* and *n*.

We have EV, EC : : RV, RD : : *m*, *n* *. * 2919.
By Converſ. and Altern. EV, RV : : CV, DV. 2922.
By Compoſ, or Diviſ. RE, RV : : DC, DV.

The ſame firſt Proportion gives by Diviſ. CV, EC : : $m-n$: n; that is, $EC = \frac{n \times CV}{m-n}$.

The Rays, which in the Glaſs are directed towards R, are in the Air directed towards F, in ſuch manner, that

RE, RV : : EC, VF* : : DC, DV. * 2930. 2989.

If for EC we put $\frac{n \times CV}{m-n}$ the Proportion is changed into this CD : DV : : $\frac{n \times CV}{m-n}$, VF; whence the Rule of N. 3030 is immediately deduc'd.

Let V be the Lenſe; R the Point of the incident Rays; E the Focus or Point of Diſperſion of parallel Rays proceeding from a contrary Part; F the Focus, or Point of Diſperſion, of the Rays coming to R is ſought of the incident Ray RB, or *r*B, BF; or B*f* is refracted; if EB, or *e*B, be the incident Ray, B*a* * will be refracted, and in direct Rays, a little diſperſed, the Angle RBE, or RB*e*, which the incident Rays make, is to the Angle, which the Rays refracted in the Glaſs make, as the Sine of Refraction in Air to the Sine of Refraction in Glaſs: So alſo the Angle, which theſe laſt in Glaſs contain, is to the Angle which the Rays refracted in the Air make, that is, to the Angle *a*BF, or *a*B*f*, as 3055. Pl. 100. F. 1, 2, 3. * 2789.

* 2809. 17 El. 5. the Sine of Incidence in the Glaſs * to the Sine of Refraction in the Air; but theſe Ratios mutually deſtroy one another; therefore the Angles are BE or BB*e*, *a*BF; or *a*B*f*; to which laſt BFU is equal. Therefore the Sine of the Angle EBR and BFU, have the ſame Ratio to the Sine of the Angle BRU.

* 2923. 2924. The firſt of theſe Ratios is that, which is given between RE and EB*, or EU. The ſecond is the Ratio which is given between RB and FB; or RU and FU; becauſe UB is ſmall. Therefore

RE, EV : : RV, FV.

By a Converſion of the Ratio RE, RV : : RV, RF. Which we had in N. 3035.

CHAP. X.

Of the Sight, where we ſhall ſpeak of the Conſtruction of the Eye.

3056. THE Properties and Laws of the Refraction of Light which we have explain'd, are of great uſe in Objects to be repreſented to our Mind.

By theſe Laws Objects are painted on the Bottom of the Eye very beautifully adorned with their proper Colours; and this Picture is the Occaſion of the Ideas, which are excited in the Mind with regard to Things ſeen, as will be ſhewn in what follows *.

* 3074. But how this Picture may be made in the Eye, cannot be explained, without examining the new Property of Light, namely the Diviſibility of the Rays exceeding our Comprehenſion.

3057. There are *ſeveral opaque Bodies*, when exactly poliſhed, except ſuch as are perfectly black, if there be any ſuch, that have the Property of dividing Light; for they *reflect the Light ſo, that the Rays* which are driven back *from every Point* are divided, and *recede every Way*; and ſo as *every Point of the Body becomes as it were a radiant Point*, from which the Light goes every Way.

3058. Hence we deduce a Method to paint Objects upon a white Plane; for all the Points of an enlighten'd remote Body, from which the Rays come upon a convex Lenſe, have their Focus behind the Lenſe *, the Foci of diſtant Objects, though not exactly, are ſenſibly at the ſame Diſtance from the Lenſe; thoſe Objects by theſe Foci may be repreſented in the ſame Plane; as was ſaid before of Flame *. This Repreſentation, as was ſaid of that, is inverted, becauſe of the Interſection of the Rays in paſſing through the

* 3011.

* 3047.

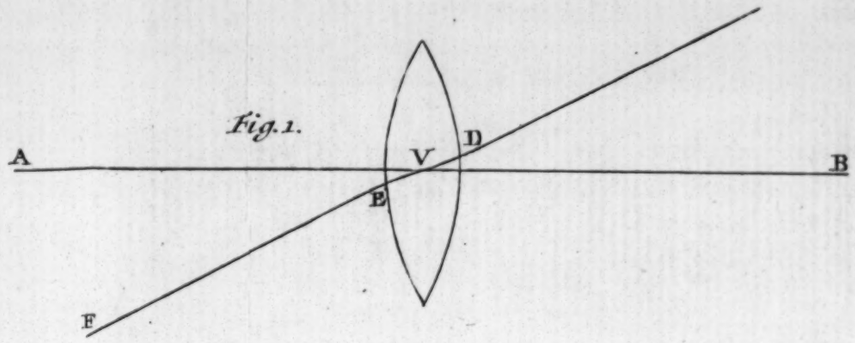


Fig. 1.

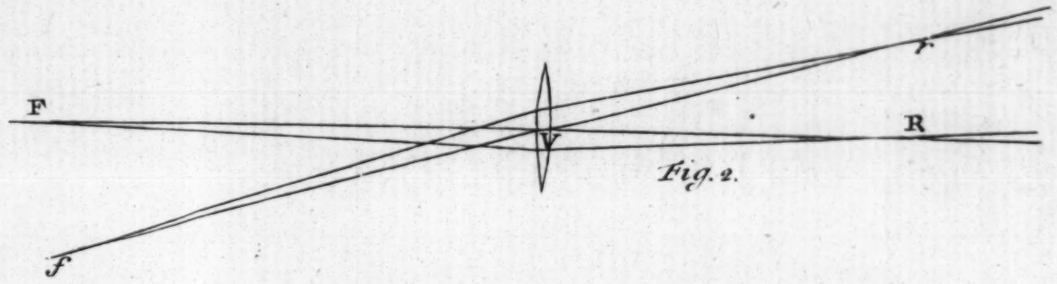


Fig. 2.

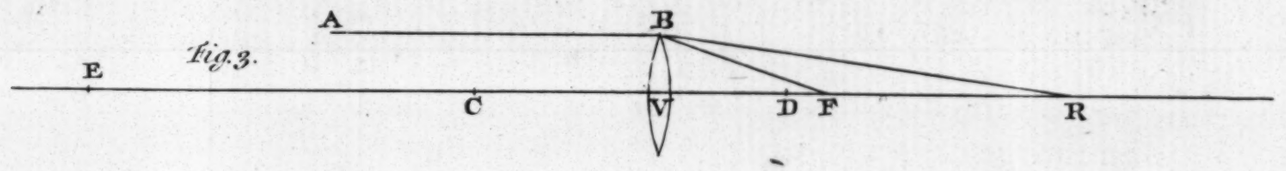


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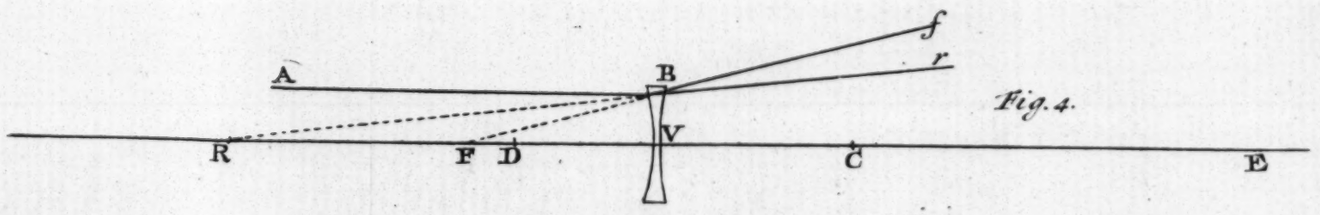
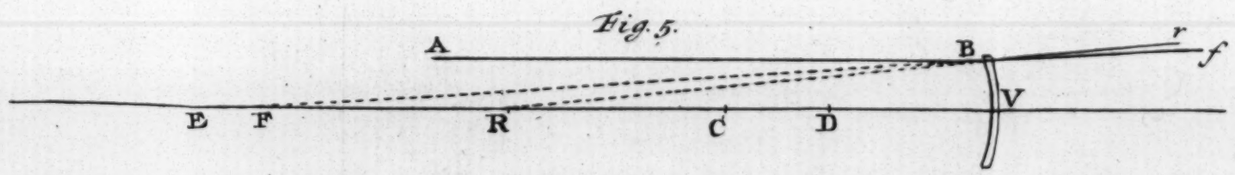


Fig. 4.

Fig. 5.



the Glaſs, and is ſenſible in a dark Place in which the Light no Way comes, but through the Lenſe, and only that by which the Objects are painted.

This will do wherever the Lenſe is placed, and in reſpect of all the Points of Objects, enlighten'd by the Rays of Light, from which right Lines may be drawn to the Lenſe without Interruption; thus we prove by the ſame Experiment the aforeſaid Diviſibility in Light, and the Aptneſs of Light to be divided by the Bodies that reflect it. 3059.

EXPERIMENT I.

Let there be a Hole in a dark Place oppoſite to ſeveral Objects, that are at leaſt fifty feet off, or farther: In this Hole place a convex Lenſe, which collects parallel Rays at the Diſtance of about four or five feet; if a white Plane be placed behind the Lenſe a little farther from it than the ſaid Diſtance, all the Objects will be painted upon it in very beautiful Colours: We muſt obſerve that by the Motion of the Plane, or of the Lenſe, the Diſtance is diſcover'd, at which the Objects are repreſented very exactly. 3060.

But the extraneous Rays muſt be intercepted; to which End, we apply at the Side of the Objects, to the Plane itſelf, in which the Glaſs is inſerted, a hollow Cylinder, in ſuch manner, that the Glaſs may be in the Middle of the Baſe, the other End being left open; the inner Surface of the Cylinder muſt be made black.

This Repreſentation of the Objects has a great Affinity with that by which the Objects which we ſee are painted in the Bottom of the Eye, as will be Evident from the make of the Eye.

The Figure of the Eye, when taken out of the Head, is almoſt ſpherical; the fore Part only being ſomewhat more convex than the other. 3061. Pl. 100. Fig. 5.

The Section of the Eye is repreſented in this Figure.

The Part A A, which is the moſt convex, is tranſparent, and called the *Tunica cornea.* 3062.

The whole Integument, or Covering of the Eye, except the Cornea, is called the *Sclerotica*, B A A B; the fore Part of the Sclerotica, which is next to the Cornea, covered with a thin Coat, is called the *Adnata*; which alſo, by Reaſon of it's Colour, is called the *white of the Eye*; the Adnata covers the Cornea alſo, but it is ſo thin there, as not to be diſcovered without Difficulty. 3063.

On the Inſide, there coheres a Coat with the Cornea, along the Circumference, called the *Uvea*, which is plane, and has a Hole in the Middle of it *pp*, which is called the Pupil. 3064.

The

The Uvea is made up of concentrical circular Fibres, interſected by ſtraight Fibres, at right Angles tending to the Center; if the firſt are ſwell'd, the laſt are relaxed, and the Pupil is leſſen'd or contracted; and a contrary Motion of the Fibres increaſes or widens it.

3065. In the middle of the Eye, but near the fore Part, there is a tranſparent ſoft Body C C, in the Figure of a convex Lenſe, whoſe hind Part is more convex than the fore Part. It is called the *chryſtalline Humour*; the Axis of it coincides with the Axis of the Eye, that paſſes through the Center of the Pupil, and that of the Bulb of the Eye.

3066. This chryſtalline Humour is ſuſtain'd by ſmall Fibres or Threads, which are fixed to all the Points of it's Circumference, and likewiſe to the Inſide of the Eye: They are bent in Figure of an Arch, and every one of them is a Muſcle, being called *Ligumenta ciliaria*, two of which are repreſented by *l* C, *l* C. They all cohere to one another, and together with the chryſtalline Humour, make a Separation in the Eye, and divide it into two Cavities, one forward *p p*, and the other backward S S.

3067. The foremoſt Cavity is fill'd with a Liquor like Water, and is call'd the *aqueous Humour*.

The hindermoſt Cavity is fill'd with a tranſparent Humour, nearly of the ſame Denſity with the aqueous Humour, but not ſo fluid, called the *vitreous Humour*.

The hindmoſt and inward Surface of the Eye is covered with a
3068. Coat, call'd the *Choroides*, which is again cover'd with a thin Membrane call'd the *Retina*.

At the back Part of the Bulb of the Eye, a little on one Side, is the optick Nerve N N, ſo join'd to the Eye, that the Eye itſelf is, as it were, an Expanſion of the optick Nerve; for the expanded Coats of the Nerve form the Choroides and the Sclerotica; and the Fibres of which the Retina conſiſts, do concur, and form the Marrow of the Nerve.

The Eye moves in the Head by ſeveral Muſcles cohering in the Sclerotica; but we ſhall not treat of them here; for as we only conſider the Eye, with regard to the Motion of Light, we deſignedly forbear taking Notice of any Thing elſe.

3069. *The Rays proceeding from any Point, and entering into the Eye through the Pupil*, go out of a leſs refracting into a more refracting Medium, through a ſpherical Surface; and therefore *if that Point be at a convenient Diſtance from the Eye*, the Rays *will converge after Refraction* * ;
* 2936. Pl.96.F.1. as in the Experiment N. 2978. in which the Glaſs V repreſents the tranſlucid Cornea of the Eye, whilſt the Water in the Box repreſents

aqueous

the aqueous Humour; and therefore, *ſuppoſing the Cornea, and the aqueous Humour, and there will be in the Eye an inverted Picture of the Objects* *. 3070. * 3057.

EXPERIMENT 2.

Let there be the Box P juſt mention'd, containing Water; let this be plac'd at the Diſtance of ſome Feet from an open Window, through which only Light enters into a Chamber; if at a certain Diſtance from the Window there be external Objects illuminated with the Sun's Rays, and that be obſerv'd, which was explained in the 15th Experiment of Chapter 8 *, we ſhall have at T the inverſe Picture of the Objects, as was explain'd concerning the Candle in the ſaid Experiment. 3071. Pl. 100. Fig. 6. * 2978.

The Picture juſt mention'd in the Eye, an Imitation of which we have in this Experiment, wou'd be at too great a Diſtance from the Cornea, and beyond the Bottom of the Eye; therefore the Diſtance is diminiſh'd *by Means of the chryſtalline Humour*, whoſe refracting Force overcomes the refracting Force of the Mediums that ſurround it; the Rays converging in the aqueous Humour, go beyond the chryſtalline Humour, into the vitreous Humour; that is, from a leſs refracting Medium, through a more refracting Medium, terminated by two ſpherical convex Surfaces, into a leſs refracting Medium; by which Motion the converging Rays converge the more *; and therefore they meet the ſooner, *and the Picture abovemention'd falls within the Eye.* 3072. 3073. * 3012.

EXPERIMENT 3.

The ſame Things being given, which were in the foregoing Experiment, put into the Box, at a ſmall Diſtance from the Aperture, through which the Light enters, a Piece of Wood, which has a convex Glaſs joined to it, which collects the parallel Rays at the Diſtance of one Inch in the Air *. To have the Picture exact, The Board T muſt be mov'd towards V. 3074. Pl. 100. Fig. 6. * 2763.

In this Experiment we have an artificial Eye, which exactly repreſents the natural Eye. The Glaſs V repreſents the Cornea, the convex vitreous Lenſe repreſents the chryſtalline; the Board T muſt be look'd upon as the Bottom of the Eye; the Water repreſents the aqueous and vitreous Humours; for the Light undergoes an equal Refraction in both theſe Humours. 3075.

The Objects, which, as has been explain'd, *are painted upon the Bottom of the Eye, are delineated upon the Retina; and by the Motion of the Light; the ſmall Fibres, of which the Retina conſiſts, are put into Motion;* 3076.

Motion; *by which Agitation we ſee the Objects themſelves.* But how this happens, muſt be explained more clearly; for which End, I ſhall now add ſeveral Things to that, which has been deliver'd
* 2310. above, concerning the Senſations *, where we treated of Sound.

3077. The Perceptions anſwer to the Motions of the Nerves *, and in-
* 2310. deed in ſuch manner, that, in a well order'd Body, there is never any Motion of a Nerve, without immediately cauſing a Perception in the Mind.

3078. Notwithſtanding *there is nothing common between the Motion of the Nerve, and the Perception, which anſwers to it.*

3079. Therefore *neither is there any Thing common* between the Object, which cauſes the Agitation of the Nerve, and the Perception, that is, *between the Perception and the Objects that are perceiv'd.*

3080. Therefore *the Senſes teach nothing of themſelves.*

3081. The Touch alone is excepted; becauſe this ſhews the different Reſiſtances of Bodies, from which we immediately learn many Things concerning Bodies.

3082. All the Senſations have this in common; that *the ſame Perceptions are* again *preſent to the Mind, as often as the ſame Circumſtances return.*

3083. Now by comparing together, what we diſcover by different Senſes, relating to different returning Circumſtances and chiefly by conſidering what the Touch teaches us, by long Experience we at laſt acquire a Faculty, whereby we diſtinguiſh many Things relating to external Objects.

3084. But *we never diſtinguiſh any Thing by the Senſes, except there be preſent a peculiar Senſation, diſtinct from every other*; which, as it
* 3082. is never regularly preſent, excepting certain Circumſtances *, the Knowledge of which we have acquir'd by long Uſe, their com-
† 3083. pariſon † being ſhewn, the Idea of the Circumſtances, that is, *the*
3085. *Idea of thoſe Things, which we diſcover concerning an Object, is join'd with the Senſation* it ſelf, *ſo as never* afterwards *to be ſeparated from it.*

In many Caſes, Men join together Ideas which have nothing common, which moreover they look upon as inſeparable, and which are join'd together by Nature; but theſe do not belong to this Place, we have ſpoken of them in our Logick; in which alſo, we have more fully explain'd, what relates to the Senſes.

But let us return to Viſion. All the Rays, which proceed from one viſible Point, meeting where that Point is painted on the Bottom
3086. of the Eye, *produce* there *a certain Agitation of a ſmall Fibre diſtinct from*

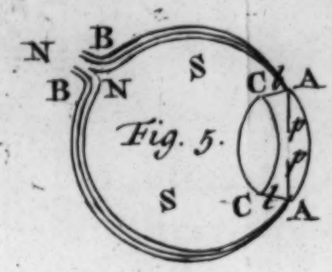


Fig. 5.

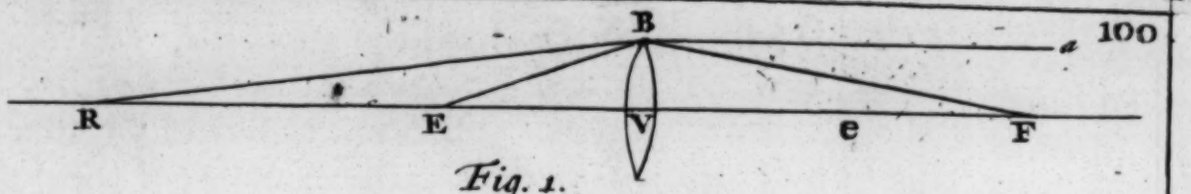


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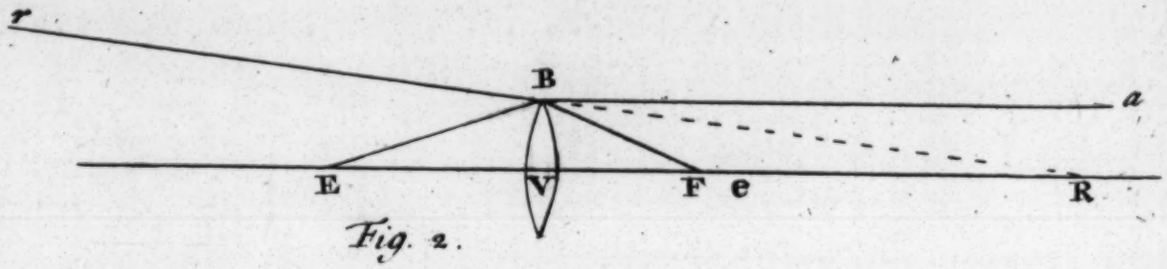


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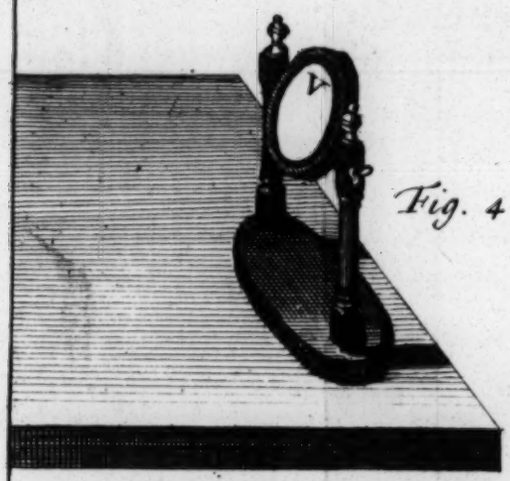


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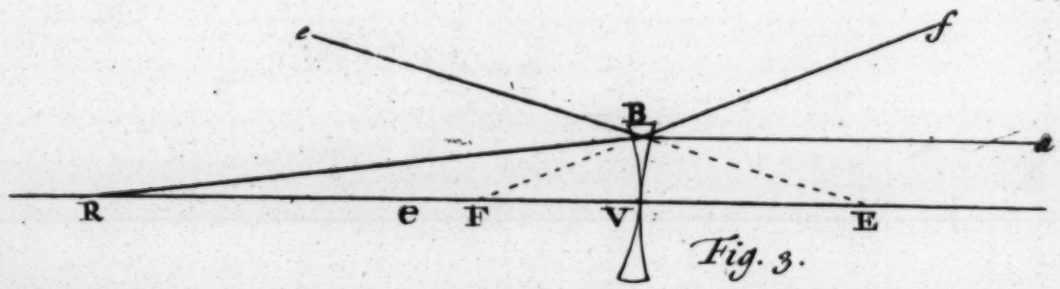


Fig. 3.

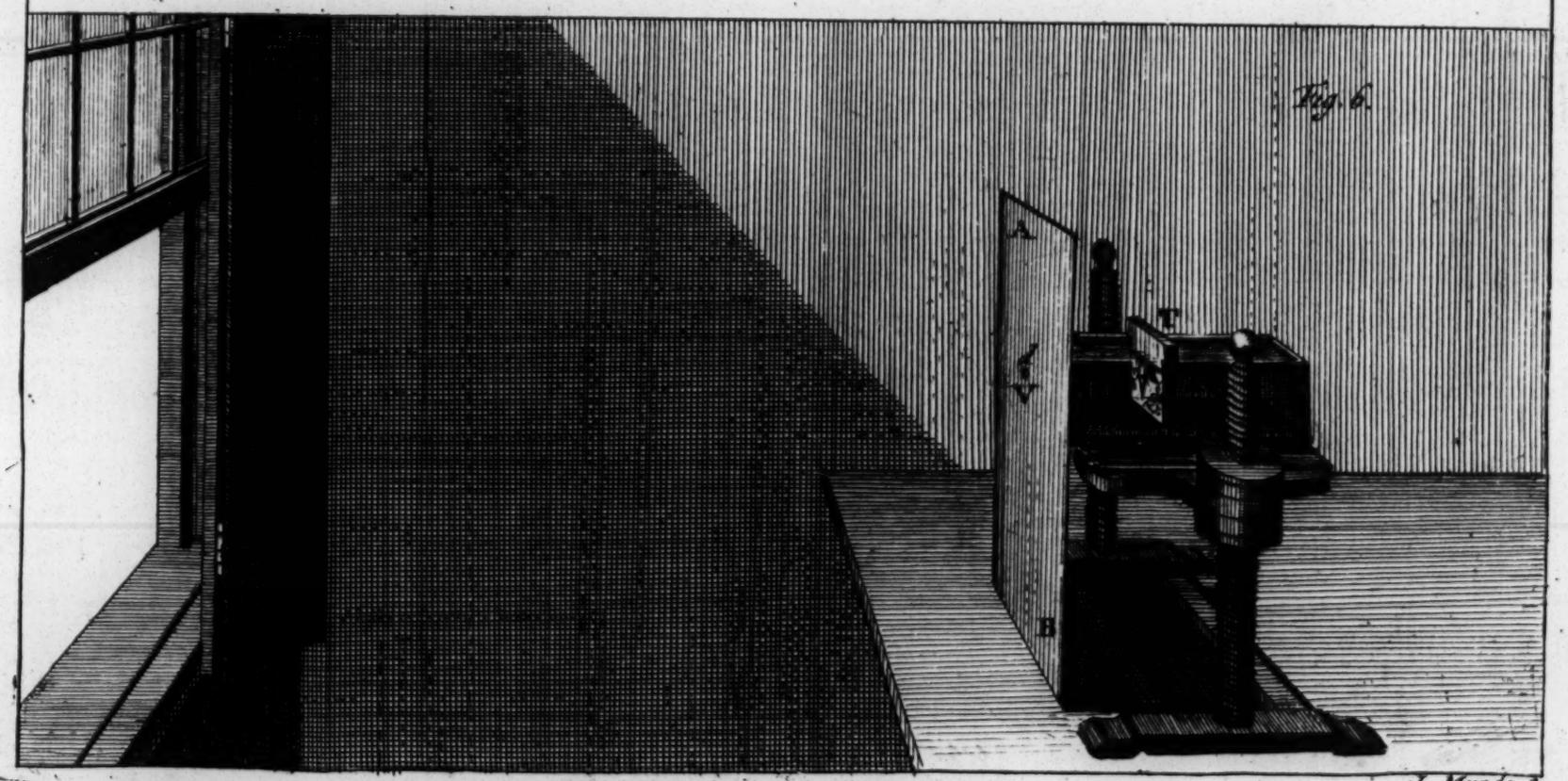


Fig. 6.

J. Myade fc.

from every other, and a like Agitation is produced by *all the Points of the Object, which is delineated in the Eye.*

Therefore *Viſion is* only *diſtinct, when the Objects are accurately painted on the Bottom of the Eye* *. 3087. * 3084.

When Rays, proceeding from the ſame Point, are not exactly join'd on the Retina, the Picture of it is not a Point, but a Spot, which is confounded with the Pictures of the neighbouring Points, in which Caſe *the Viſion is indiſtinct.* 3088.

But as, *according to the various Diſtance of the radiant Point*, it's Focus is more or leſs removed *, *it is neceſſary, that there be a Change in the Eye*, that the Place in which the Picture is exact may not fall before or behind the Retina, and *that the Viſion be not confus'd.* 3089. * 2936.

There are ſeveral Opinions of Philoſophers concerning this Alteration of the Eye; on which I ſhall make this general Obſervation, that *it is not at all probable, that the Figure of the whole Eye is alter'd, in order to remove further or bring nearer the Retina*, and that the Alteration is to be ſought for in the Inſide of the Eye. 3090.

For if the Figure of Eye ſhould be changed, as this Change is equally neceſſary in all Animals, of which we are ſpeaking, the Figure of the Eye will undergo the ſame Changes in all Animals; for we do not find different Cauſes of the ſame Effect in Nature. But in the Whale the Sclerotica is too hard to be liable to Alteration. Moreover if there be ſuch an Alteration in the whole Eye, it will ariſe from the Preſſure of the external Muſcles, which are different, according to the different Poſition of the Eye, and regular in one Caſe only. 3091.

Beſides there cannot be a Change of Figure great enough, that Viſion may be diſtinct at the Diſtance of an hundred Feet, and at the Diſtance of two Inches; but there are Men whoſe Eyes are alter'd enough, to ſee diſtinctly in theſe different Circumſtances; which cou'd not be, without almoſt doubling the Length of the Eye, if we attribute diſtinct Viſion to this Cauſe. 3092.

Now if we examine the Inſide of the Eye, it will appear that the Alteration is neceſſarily in the Chryſtalline; which by a Removal in the Eye, or by an Alteration of it's Figure, will produce the deſired Effect; for the Rays, which cut the Retina before they meet, wou'd meet on the Retina if the chryſtalline Humour * becomes more convex; or if, it's Figure being kept, it be carried more to the fore part of the Eye. 3093. * 3007.

It is plain from this that *the Poſition of the chryſtalline Humour is* eaſily *altered, and* that *it approaches towards the Retina, and recedes* 3094.

cedes from it, it's Axis remaining, becauſe the ciliary Ligaments are muſcular: When theſe Muſcles are inflated and become ſhorter, the Cavity which is form'd at C *l*, C *l*, from the Inflection of theſe Ligaments is diminiſhed; whereby the vitreous Humour is compreſs'd, which itſelf preſſes upon the chryſtalline Humour, and drives it forwards, and increaſes its Diſtance from the Retina; which is requir'd in the Viſion of near Objects *.

* 2936.3011.

3095. But this Removal is not ſufficient; therefore there is alſo another
3096. Alteration in the Eye. But this ſecond Change belongs to the Chryſtalline alſo; which, *when* it is drawn by the ciliary Ligaments,
3097. whereby *it recedes from the Bottom of the Eye, becomes more plain*; wherefore *there is requir'd a greater Change of Figure, than if it kept it's Poſition always the ſame*; that is, the Alteration is more ſenſible,
* 3110. which we ſhall ſee is of a certain Uſe *; which nevertheleſs, in
† 3112. Men that have two Eyes, is for the moſt part ſmall *.

Theſe Alterations in the Eye have their Limitation, thence alſo
3098. the *Objects appear diſtinct only within certain Limits, at different*
3099. *Diſtances, according to different Eyes; and very often, in the ſame Man, but yet have not the ſame Limits*; which is of almoſt the ſame Uſe, as if the Limits for both Eyes were at a greater Diſtance from one another; for it is ſufficient to ſee an Object diſtinctly with one Eye only.

3100. In ſome alſo the neareſt Limit with reſpect to one Eye is at a greater Diſtance, than the more remote Limit with reſpect to the other Eye; in this Caſe the near Objects, and thoſe that are very remote, are ſeen diſtinctly, the intermediate ones appear confuſed.

3101. The Picture at the Bottom of the Eye is inverted, as has been
* 3070. ſaid *, whence it is enquir'd, why Objects appear erect? To this we anſwer by another Queſtion; whether a Perſon can better conceive the Connection between the Idea in the Mind and an erect Figure, than an inverſed one? We muſt confeſs that we conceive no Connection in either Caſe: But by Experience we acquire a Faculty of judging concerning Objects by Means of their Senſation,
* 3082. which always become preſent, when like Circumſtances return *; and it matters not in what Poſition the Fibres are, if the Senſations in different Circumſtances be but different, and the ſame in the ſame Circumſtances. Our Mind does not behold the Picture being plac'd in a Corner; our Mind joins with certain Senſations,
* 3085. Ideas acquir'd elſewhere *.

3102. *If we behold the ſame Objects with both Eyes, only one appears*; and that in that Caſe only when the Object is painted on correſpondent

dent Points of the Retina. This is by ſome attributed to the meeting of the optick Nerves; they affirm that in thoſe Animals, who ſee the ſame Object with both Eyes, the optick Nerves meet, before they arrive at the Brain to which they arrive when they are ſeparated again.

But this is not the true Cauſe; for in the Cameleon, who directs one Eye towards the Sky, whilſt he beholds the Earth with the other Eye, the Nerves are confus'd in the ſame manner, as in Man; though generally in Animals, that behold different Objects with each Eye, the optick Nerves are ſeparated from the Eyes to the Brain. 3103.

The true Reaſon why one Point only appears, is Experience; which has conſtantly taught us, that the two Senſations ariſing from correſpondent Points of the Nerves proceed from one Point; and thus being join'd together in the Mind, theſe two Senſations are now join'd with the Idea of a viſible Point, ſo that they cannot be ſeparated by us; as the Senſation, ariſing from one only Agitation of the Nerve, is confounded with the Idea of a viſible Point, and thus it is manifeſt that the two Senſations may be confounded with the ſame Idea; if it ſhall appear by conſtant Experience, that theſe always depend upon one viſible Point only. 3104.

Therefore the correſpondent Points are thoſe, on which the ſame Point is painted in both Eyes at the ſame Time. Theſe Points may differ in different Men, they may alſo vary in the ſame Man; for if the Poſition of the Chryſtalline be alter'd by a Blow, or any other Way, or if the Eye undergoes any other Alteration, the Picture of the Point may fall upon another Fibre, other Things remaining the ſame; the Object in this Caſe appears double; but in a Length of Time this Inconveniency diminiſheth, and at laſt, after a long Experience, vaniſheth. 3105.

But in well diſpoſed Eyes the correſpondent Points are in Circles parallel to one another, and which, in each Eye, paſs through the Point in which the Axis of the Eye paſſes through the Retina, and in theſe Circles are equally diſtant on both Sides from theſe Points. 3106.

Only one Point can be ſeen diſtinctly at the ſame Time, namely, that which is repreſented in the Axis of the Eye; this only is painted by direct Rays; in the other the Rays are oblique, and the Viſion leſs diſtinct *. 3107.

* 2987. 3042.

Therefore, when we behold a Point with both Eyes, we direct the Eyes in ſuch Manner, that the Axis of both Eyes continued may meet in it; we eaſily perceive that this is the Caſe, when we 3108.

fix our Eyes upon any Point; otherwiſe we view ſeveral Points ſucceſſively with our Eyes, by directing our Eyes in ſuch Manner, that now one and then another may be diſtinctly repreſented in both Eyes; but when this is done on a ſudden, inſtead of all the Points of an Object, not very much extended, we do as it were diſtinctly ſee the whole Object at one View.

3109. It is manifeſt that there are different Senſations, and for various Reaſons, from the Light running againſt the Fibres of the Retina; but theſe are not ſufficient, we ought to have regard to other Things, in the judging of Diſtances; but that we may diſcover the Figures of Objects, and judge of their reſpective Situation; we ought to know the Diſtances of all the Points from the Eye.

3110. When we behold a Point, the chryſtalline Humour puts on a peculiar Figure, which is different, according to the different Diſtance
* 3089.3096. of the Point, and is always the ſame at equal Diſtances *; but as this Alteration of the Chryſtalline is inſeparable from a certain de-
3111. termined Senſation, *we acquire by Uſe a Faculty of judging of Diſtance*; which we always conceive the ſame as often as there is the ſame Senſation.

But this is of uſe only, *when the Diſtances are ſmall*; for then the
3112. Alterations are greater. But *when their Diſtances are a little greater, the Judgment concerning them is leſs certain with one Eye*; becauſe as we are leſs accuſtomed to judge of Diſtances with one Eye, the ſmaller Alterations are not enough ſenſible to us.

3113. When we behold a Point with both Eyes, we direct the Axes of both to this Point, ſo that the Axes are more or leſs inclin'd to one
* 3108. another, according to the leſs or greater Diſtance of the Point *. This Alteration of the reſpective Poſition of the Eyes is ſenſible to us, and indeed in ſuch Manner, that it is join'd with Pain if we only conſider a near Point remov'd to the Diſtance of three or four Inches only. Therefore without Attention we acquire by Uſe a
3114. Faculty of judging of Diſtance, *from the Direction of the Axes*, which is ſenſible to us, becauſe it depends upon a Motion of the Eye that is ſenſible to us. Therefore we ſee the Uſe of two Eyes plac'd at a certain Diſtance from one another; *as long as this Diſtance of the Eyes has a ſenſible Ratio to the Diſtance of Objects the Judgments made concerning this Diſtance is certain enough.*

3115. *Judgment is made concerning great Diſtances from the apparent Magnitude, Colour, and other Circumſtances:* If we conſider known Objects, which alſo we owe to Experience; for we call to our Aſſiſtance every thing that is known to us concerning an Object, when the Mind judgeth of it's Diſtance.

It

It is impoſſible to judge of very great Diſtances, except the ſame Object be ſeen from different Places. 3116.

The apparent Magnitude of an Object, depends upon the Magnitude of the Picture on the Bottom of the Eye; which depends *upon the Angle, under which the Object is ſeen*; that is, which is made by Lines drawn from the Extremities of the Object to the Eye. 3117.

The ſaid apparent *Magnitude* muſt be diſtinguiſhed from the Magnitude, *which our Mind attributes to an Object ſeen*; this laſt depends upon the Judgment which is not founded upon that Appearance only; but is deduc'd from all, that is known to us concerning the Object. Every one knows, for Example, that the Object appears the leſs, according as it is more diſtant; from whence it is, that *according to the greater Diſtance of the Object*, if it be known, the apparent Magnitude of the Object *is increaſed* in the Judgment ariſing in the Mind, which is done indeed without our perceiving it. Therefore the ſame Object, at the ſame Diſtance, appears of a different Magnitude, if we judge differently of the Diſtance. 3118.

The Sun and Moon are remarkable Examples of this, which appear greater when they are near the Horizon, than at a greater Height; though, as Aſtronomers know, the Sun's Picture in the Bottom of the Eye is the ſame in both Caſes, and that of the Moon is leſs, when it appears greater near the Horizon; we cannot judge of the Diſtance *; but it appears greater nearer the Horizon, becauſe of the Interpoſition of Fields and the Heavens. But it plainly appears that this is the true, and only Cauſe of this Phenomenon, if we look at the ſame Bodies through a Tube; this apparent Diſtance vaniſhes, and with it the Magnitude deduc'd from it. But from our Infancy, and ever after, we get a Habit perpetually of joining the Idea of Diſtance with the Increaſe of apparent Magnitude (which is neceſſary to make a true Judgment concerning the Magnitude) by which theſe Ideas are ſo cloſely connected, that they cannot be ſeparated *, not even in thoſe Caſes in which we know they lead us into Error. 3119.

* 3116.

* 3085.

CHAP.

CHAP. XI.

Of Viſion through Glaſſes, and the Corrections of ſome Faults of the Eyes.

3120. AN Object is viſible, becauſe all it's Points are radiant Points *;
3121. therefore *a Point appears in that Place from whence diverging Rays are emitted* †. Except as far as we ſuppoſe another Di-
* 3076. ſtance, by reaſon of different Circumſtances; for we ſpeak here of
† 3111. Viſion with one Eye only, and the Judgment is uncertain *.
* 3112.

3122. *If Rays any how inflected, enter the Eye diverging, the viſible Point will be in the imaginary Focus of the Rays*, for theſe Rays enter the Eye exactly in the ſame Manner as the Rays which came directly from the Focus would do; and the ſame Situation of the chryſtalline Humour is required in order for them to unite in the Retina: So that in regard to a Spectator it matters not whether thoſe refracted Rays, or thoſe direct Rays, enter the Eye, and there will be the ſame
* 3089. 3111. Motion in the Eye when it fits itſelf for diſtinct Viſion *.

3123. *A Point appears the more enlighten'd, the greater the Number of Rays coming from it is, that enters the Eye.*

3124. I ſhall ſay nothing of the Magnitude and Diſtance, which we attribute to an Object ſeen through Glaſſes; I ſhall only ſpeak of the apparent Magnitude and of the Diſtances, to which the Points are remov'd, from which the Rays ſeem to come, by which the Points of the Object are painted upon the Retina. Every thing elſe is uncertain, and, what is deliver'd by Optick Writers concerning this Matter, often contradicts Experience. Different Men, in the ſame Circumſtances, judge differently of theſe Things; and the ſame Man, whilſt he beholds equally remote Objects ſucceſſively through the ſame Glaſs, the Eye being placed at the ſame Diſtance, does not always judge of their Magnitude and Diſtance in the ſame Manner.

3125. But it appears from other Things how uncertain the Judgment concerning Diſtance is; let any one look at an Object through a Glaſs, and judge of the Diſtance, and let him place the Object and Glaſs in ſuch Manner, that a Point of the Object may be ſeen in a Limb itſelf of the Glaſs, whilſt no Part of the Object is ſeen without the Glaſs; let him alſo bring near another Object in ſuch Manner, that he may perceive this without the Glaſs, with the ſame Eye, with which he ſees the Object through the Glaſs, and in-

deed, ſo that the Objects may appear join'd, and he may ſee nothing of this Object in the Glaſs; and that both Objects may appear in the ſame Plane; if then, the Glaſs being remov'd, a Spectator judges of the Diſtance of the laſt Object, this will not appear the ſame as that, which he judg'd of the Object ſeen through the Glaſs.

Objects that are ſeen through a plane Glaſs, terminated by two parallel Planes, appear to be nearer than when view'd with the naked Eye. 3126. Pl. 101. Fig. 1. Let A be a viſible Point; the Rays going from it and entering the Eye are between A *b* and A *b*; theſe being refracted in the Glaſs V V, move along *b c*, *b c*; and go out through *c d*, *c d*, which are parallel to the Lines A *b*, A *b* *: But becauſe *b c*, *b c* are refracted towards the Perpendicular †, *c d*, *c d*, fall between *b* A and *b* A; that is, they cut one another in *a*, which is leſs diſtant than A; therefore the imaginary Focus of the Rays, which enter the Eye, is at *a*, in which the Point A appears to be *. * 2792. † 2787. * 3122.

The ſaid *Point* alſo *appears more enlighten'd.* 3127. For all the Rays that are between A *b* and A *b* enter the Pupil between *d* and *d*; but ſince the Lines A *b* and A *b* are parallel to the Lines *c d*, *c d*, and theſe Lines are between thoſe, A *b* and A *d* being continued, would fall beyond *d*, and *d*; and ſo if the Glaſs was taken away, the Rays which now enter the Pupil would take up a greater Space, and conſequently would not all enter the Eye. Every Point that is brought nearer to the Eye, appears more enlighten'd, and thus the Caſe is in this Matter; for if the Pupil, it's Aperture remaining, ſhould not be at a greater Diſtance from the Point A, than it is now remov'd from the Point of Diſperſion *a*, the ſame Rays would enter the Pupil, which follows from the Equality of the Angles *b* A *b*, *c a c*, made by the parallels *b* A, *c a*, and *b* A, *c a*.

*The apparent Magnitude of an Object * is increaſed when ſeen through a plane Glaſs.* 3128. Pl. 101. Fig. 2. The Object A E is ſeen by the naked Eye, under the Angle A *d* E; but upon the Interpoſition of the Glaſs V V, by reaſon of the Refraction through A *b c d* and E *b c d*, it appears under the Angle *c d c*, which is greater than the laſt. * 3117.

The Increaſe of the apparent Magnitude 3129. is the greater, the more the Angles A *d* E, and *c d c* differ; whoſe Difference *increaſes* with the Acceſſion of the Interſections of the Lines A *d*, *b c*, and E *d*, *b c*, towards the Points *b* and *b*; this obtains *in the Acceſſion of an Object towards the Glaſs*; and therefore it is greateſt of all, when the Object touches the Glaſs; which proves that Objects inclos'd in the Glaſs itſelf appear magnified alſo.

3130. And in general, *when the Eye is plac'd in a leſs refracting Medium, the Object that is ſeen in a more refracting Medium appears*
* 2891. *bigger, and by the Refraction is brought nearer too* *. Theſe Things are confirm'd by daily Experience, with reſpect to Objects ſeen in Water.

3131. Let there be *a Point* A *ſeen through a convex Lenſe* V V, the Object
Pl. 101. being plac'd between the Glaſs and the Focus of parallel Rays pro-
Fig. 3. ceeding from the Side of the Eye, the Rays *A b*, *A b*, go out leſs
* 3011. diverging at *c d*, *c d*, namely as if they proceeded from *a* *; and
† 3122. therefore the viſible Point *is remov'd to a greater Diſtance* †. *It*
3132. *appears more illuminated alſo*; for the Rays approach nearer to one
* 3007. another by paſſing through the Glaſs *, and are reduc'd into a leſs Space; wherefore they enter into the Pupil in a greater Number alſo.

3133. The apparent Magnitude of *an Object*, if the Eye be not ap-
Pl. 101. plied to the Lenſe, is alſo increas'd; that is, the Object, in the
F. 4, & 5. Circumſtances mention'd, appears under a greater Angle *beyond the convex Glaſs*, which is evident by the Inſpection of the Figure: The Object A E, ſeen with the naked Eye, appears under the Angle A *d* E; but now it appears under the Angle *c d c*, which is greater: For (in Fig. 4.) the converging Rays *A b*, *E b*, do converge
* 3012. more as they go out of the Lenſe *, or diverging (in Fig. 5.) do
† 3011. come to the Eye converging †, therefore the Object *appears magni-*
3134. *fied*; but, as has been already obſerv'd *, *the Magnitude which we*
* 3124. *attribute to an Object is not in the ſame Proportion with the apparent*
† 3118. *Magnitude* †.

3135. Objects are not always viſible through a convex Glaſs. For *that a Point may appear diſtinct, it is required that the Rays proceeding*
* 3121. *from that ſhould enter the Eye diverging* *, *and that the imaginary Focus of thoſe Rays, in regard to the Spectator, ſhould fall within*
* 3122.3098. *the Limits of diſtinct Viſion* *. If the Object be removed beyond
3136. the Focus of parallel Rays, the Rays coming from a Point of the
* 3011.3035. Object, enter the Eye converging *; which Caſe is impoſſible to the naked Eyes; in this the Viſion is always confuſed.

3137. *If in this Caſe the Eye be ſo remov'd, that the Rays, proceeding from a viſible Point, meet by Refraction, before they come to the Eye*, there are radiant Points in all the Points, in which the Rays meet, namely the Foci of all the Points of the Object, whereby the Object is re-
* 3058. preſented inverted upon a white Plane *, and which are the viſible Points with reſpect to the Eye to which the Rays can come after
* 3121. Interſection *. In this Caſe *the Object appears inverſe*; becauſe we

do not ſee the Object itſelf but the Repreſentation of it behind the Glaſs, which we ſaid was inverſe * ; and we carry this beyond the Glaſs in Imagination. * 3058.

We have ſaid that the Caſe is impoſſible to the naked Eye, in which the Rays coming from a Point enter the Eye converging ; and ſo ſuch a Viſion is always confuſed ; becauſe the Make of the Eye cannot adapt itſelf to an impoſſible Caſe : Yet ſometimes, but rarely, in this Caſe too, Objects appear diſtinct ; which as it proceeds from a Fault of the Eye, by which all diſtinct Viſion is taken away from the naked Eye, I did not think it neceſſary to take Notice of theſe Exceptions of the general Rule. 3138.

The Fault of moſt Old Men's Eyes is, that they ſee remote Objects diſtinctly, and near ones appear confuſed ; which fault *is corrected by the Interpoſitiou of a convex Lenſe.* The Rays flowing from a Point which is near meet beyond the Retina ; paſſing through a convex Glaſs, they will diverge leſs as they enter the Eye, and ſo meet within the Eye ſooner ; that is, come to the Eye, as if they came from a Point more remote, ſuch as is ſeen diſtinctly by an old Man. 3139.

Objects appear to be nearer, leſs enlighten'd, and leſs when ſeen through a concave Glaſs. 3140.

The Rays A *b*, A *b*, and all the intermediate ones, going through a concave Lenſe, become more divergent *, and enter the Eye as if they came from a leſs diſtant Point *a* †, to which the viſible Point is transferr'd ‡. 3141. Pl. 101. F. 6. * 3021. † 2877. ‡ 3122.

Upon the increaſing the Divergency of the Rays, they are more diſperſed, and therefore they enter the Eye in a leſs Number, which leſſens the Clearneſs of the Point *. 3142. * 3123.

The apparent Magnitude is alſo leſſened, becauſe the Rays A *b*, E *b*, by which we ſee the Ends of the Objects, enter the Eye leſs converging *, and ſo the Angle *c d c*, under which the Object is ſeen behind the Glaſs, is leſs than the Angle A *d* E, under which it appears to the naked Eye : Therefore the Object will appear leſs *. 3143. Pl. 101. F. 7. * 3022. * 3117.

A concave Lenſe is proper for thoſe who only ſee near Objects diſtinctly ; ſuch are called Myopes, or are ſaid to be pur-blind ; remote Points appear through this Lenſe to be near * ; and the Rays which concurred before they came to the Retina, now entering more diverging, do meet upon the Retina. 3144. * 3140.

From all this we ſee, if we ſet aſide the Clearneſs of the Objects, becauſe through the Glaſs, as by the naked Eye, it depends upon the variable Magnitude of the Pupil, that all the Differences may 3145.

be brought to two, which are between the Viſion through the Lenſe, and the Viſion to the naked Eye; there is a Removal of the viſible Point, and the apparent Magnitude of the Object is alter'd,
3146. that is, the Picture at the Bottom of the Eye is alter'd. We determine this Removal of the viſible Point by the Rule deliver'd in Number 3035, concerning the Refraction of Light in it's Paſſage through a Lenſe.

But the Proportion between the Picture, ſeen by the naked Eye, and this, the Lenſe being made uſe of, is diſcovered by the follow-
3147. ing Method; from whence it follows that *there is no Difference between theſe Pictures, when the Eye, or the Object, is apply'd to the Lenſe itſelf.*

3148. Let V be a convex or concave Lenſe, O the Eye; AB the Object;
Plate 102. F the Point of parallel Rays, proceeding from the Side of the Object.
F. 1, 2, 3. Let there be ſought a fourth Proportional VG, to FV, FO, VA; let G be mark'd in ſuch Manner, that V may be with reſpect to A and G, as F is with reſpect to O and V, then OG will be to OA, as the Image without the Glaſs to the Image of the Object ſeen
3149. through the Glaſs; and *this Proportion is not alter'd, though the Eye and the Object be tranſpoſed* in ſuch Manner that their Places are changed.

3150. In the concave Lenſe (Fig. 3.) OG exceeds OA, and the Object is diminiſh'd; if the Lenſe be convex and O be between F and V (Fig. 1.) the Image is always increaſed.

3151. If O coincides with F, G coincides with V, and the Ratio ſought is that which is between FV, and FA.

3152. That is, the Eye being placed in the Focus of parallel Rays, the Picture of the Object through the Glaſs, at what Diſtance ſoever we ſuppoſe this placed, is equal to the Picture of the ſame Object ſeen with the naked Eye at the Diſtance of the Glaſs placed
3153. from the Eye; for *the Repreſentation of a Fire ſeen with the naked Eye encreaſes as the Diſtance of that from this is diminiſhed*; for the apparent Magnitude follows the Ratio of the Angle under which
* 3117. the Object is ſeen *, and this Angle, the Line remaining, which is the Baſe of it, is diminiſh'd, as the Baſe recedes; becauſe we ſpeak of the ſame Angle.

3154. The Eye being remov'd further (Fig. 2.) beyond F, the Phenomena are different according to the different Situation of the Object, as will be ſeen in the Scholium following; in which we ſhall demonſtrate what has only been mention'd here.

There

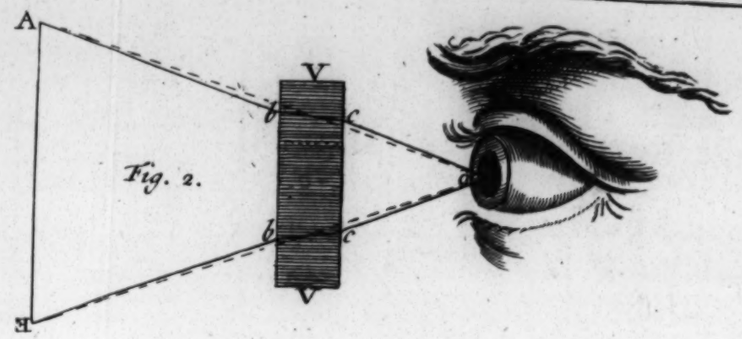


Fig. 2.

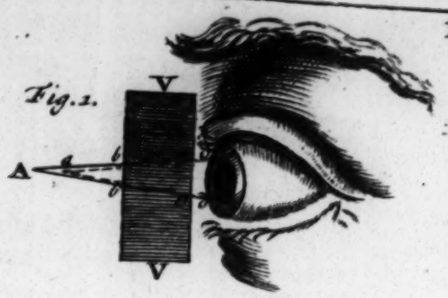


Fig. 1.

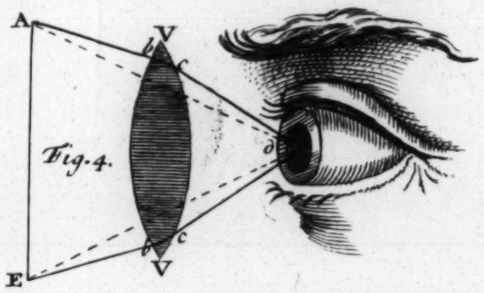


Fig. 4.

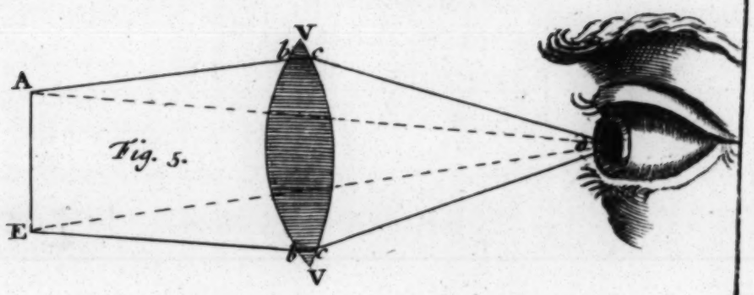


Fig. 5.

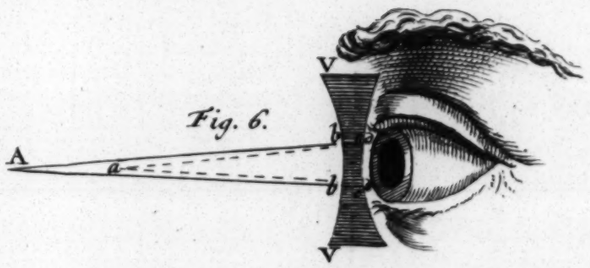


Fig. 6.

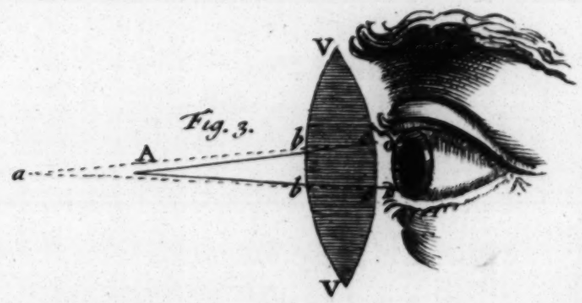


Fig. 3.

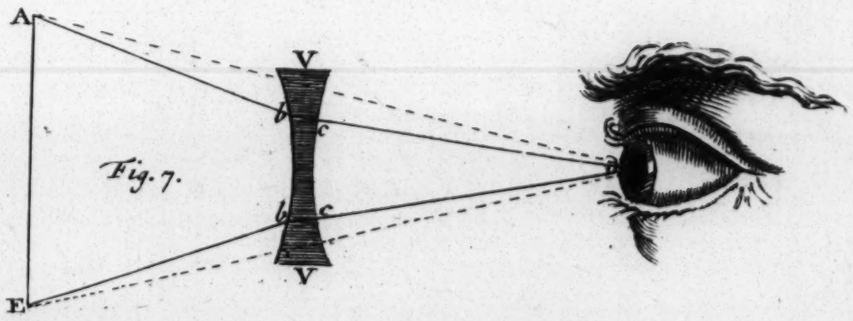


Fig. 7.

J. Mynde f.

Fig. 1.



Fig. 4.

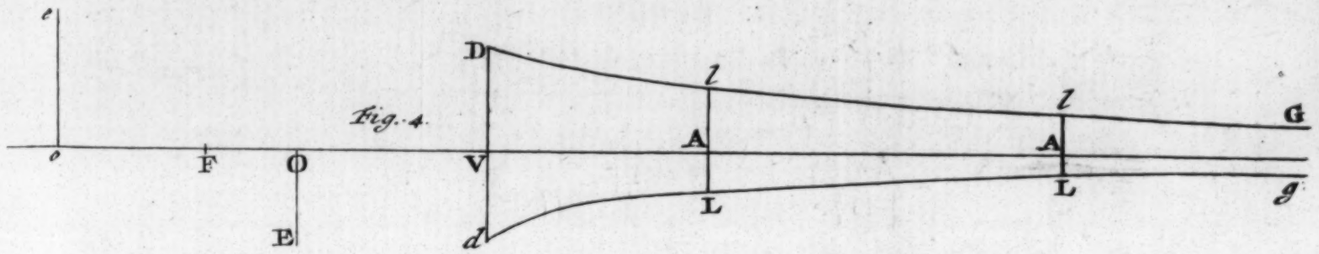


Fig. 2.

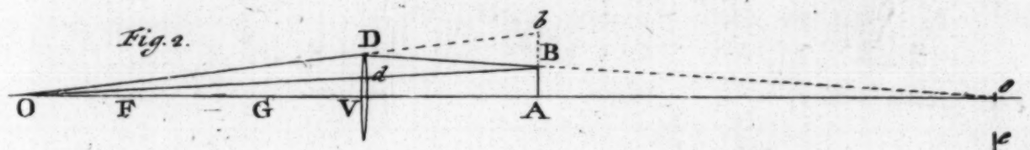


Fig. 5.

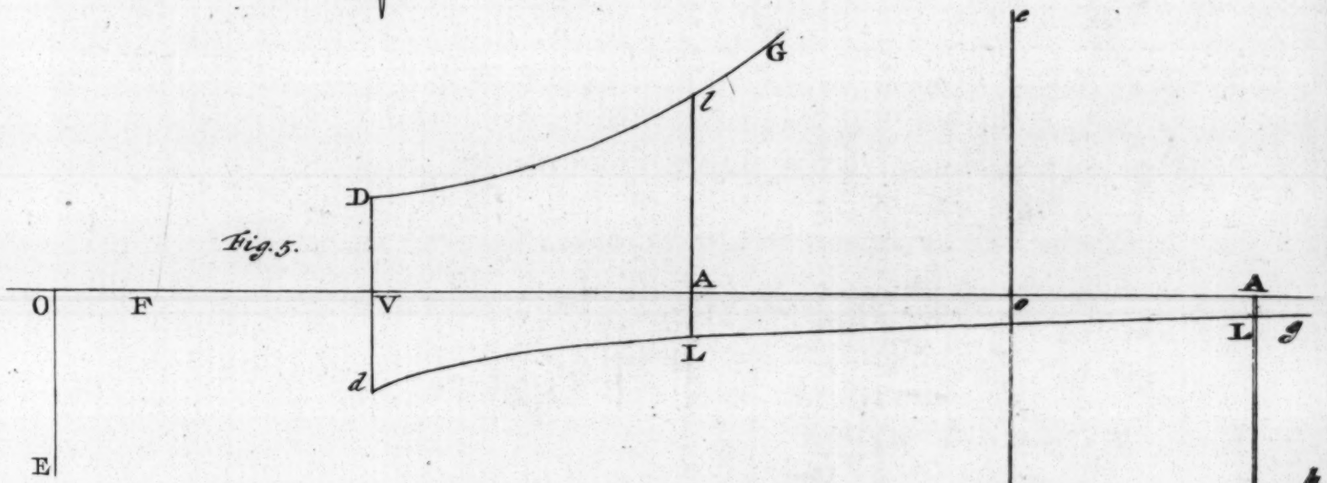


Fig. 3.

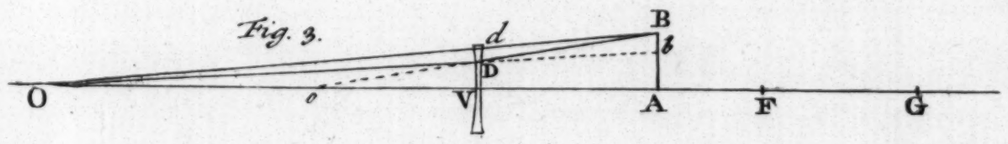
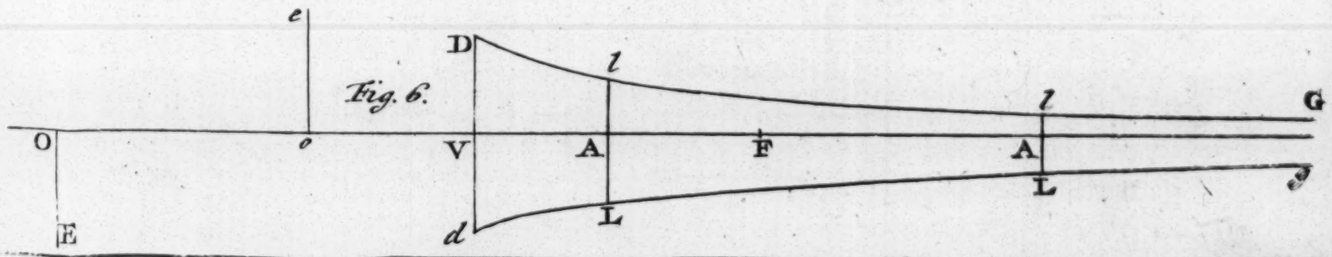


Fig. 6.



There are Glaſſes that have one Surface plane, and on the other Side there are ſeveral plane Surfaces that make Angles with one another; through theſe the Rays proceeding from the ſame Point ſuffer different Refractions; and by every Surface are made to enter the Eye in a different Direction, as if they came from a different Point: That is, the ſame Point forms ſeveral imaginary Foci; and therefore appears multiplied: For it is ſeen in ſeveral imaginary Foci *: Which as it happens in reſpect of every Point of the Object, *through* ſuch *a Polyhedrous Lenſe, the Object appears multiplied.* 3155. * 3122. 3156.

SCHOLIUM.

Of the Alteration of the apparent Magnitude.

WE have ſeen that the apparent Magnitude of an Object, ſeen through a Lenſe, is alter'd *. I ſhall now demonſtrate the Method, by which I ſaid this Alteration was determin'd †. 3157. * 3133 3140. † 3148.

But we muſt firſt obſerve, that the Amplification, or Diminution of an Object, is not the ſame through the whole Lenſe; but we neglect a ſmall Difference; we have determin'd the Alteration of that Part of the Object, through which the Axis of the Lenſe paſſes; that is, we have conſider'd only thoſe Points of the Object, that are near the Axis; of which only I ſhall now ſpeak. 3158.

Suppoſing what was mention'd in N. 3148. moreover let *o* be the Point to which the Rays come, which being refracted meet at *O*, where the Eye is plac'd; therefore drawing B *o*, which comes to the Lenſe at D, the Ray B D is refracted along D O, the Line A B of the Object appears under the Angle D O V; to the naked Eye the ſame is ſeen under the Angle B O A. 3159. Plate 102. Fig. 1, 2, 3.

Therefore the Picture in the Eye, when a Glaſs is put between, is to the Picture in the naked Eye, as V D is to V *d*; whoſe Ratio is made up of the Ratios of V D to A B, and A B to V *d*. 3160.

The firſt is the Ratio of *o* V to *o* A, the ſecond is that between O A, O V. 3161.

We have V A, V G : : F V, F O * : : *o* V, O V †. * 3148.

By Alter. Comp. or Diviſ. and laſtly by Inverſ. *o* V, *o* A : : O V, O G. † 3055.

Therefore the ſaid compound Ratio is made up of theſe two Ratios of O A to O V and O V to O G, which is the ſame Ratio as that between O A and O G, as has been ſhewn in the ſaid N. 3148.

Let us now ſuppoſe the Eye and Object to be tranſpoſed, the Eye to be placed at A, the Object at O; the Rays, that proceed from the Point O of the Object, enter the Eye as if they proceeded from *o*, as follows * * from the determination of this Point †; wherefore, inſtead of the Object at O, we ſee it's Image at *o*. In the Caſe of Fig. 2, the Rays converging from all the Points of the Image, make a confus'd Picture in the Bottom 3162. * * 2789. † 3159.

* 3136. of the Eye *, but, as it is manifeſt, the Magnitude of the Picture of the Image is the ſame, whether it be before, or behind the Eye, if the Diſtance and Magnitude of it do not differ.

3163. *The linear Magnitude of the* ſaid *Image is to the linear Magnitude of the Object itſelf, as the Diſtance of that to the Diſtance of this from the Glaſs*; that is, as V*o* to V O; as follows from Number 3045; from which we

3164. alſo deduce in general, that *the Object remaining, the Diameter of the Image follows the Ratio of the Diſtance of it from the Glaſs.*

3165. *The Picture of a Line in the Bottom of the Eye*, if it be perpendicular to the Axis of the Eye continued, ſuch as the Lines conſider'd here, *is increas'd and diminiſh'd with this Line, and follows* the Proportion of it.

The ſame Picture is increaſed as the Eye approaches, and the contrary, and it follows *the inverſe Ratio of the Diſtance of the Object from the Eye*,

* 3153. as has been ſeen above *.

Therefore, in the Caſe of which we are ſpeaking, the apparent Magnitude through the Glaſs, that is, the Magnitude of the Picture of the Image, is to the Magnitude of the Picture of the Object in the naked Eye, in a Ratio compounded of the Ratio between *o* V and O V directly, and of that between *o* A and O A inverſly; which is the Ratio of the Rectangle made of *o* V and O A to the Rectangle made of O V and

* 23. El. 6. *o* A *, which is the ſame Ratio that we had above, before the Eye and

† 3161. Object were tranſpos'd †.

3166. Again Let V be a convex or concave Glaſs, as in N. 3159; O the Eye; *o* the Point to which the Rays come, which proceed from the Eye; A B the Line of a determin'd Magnitude in the Object, which we ſuppoſe moveable.

The apparent Magnitude of the Line A B, to the naked Eye, follows

* 3153. the inverſe Ratio of the Diſtance O A *, therefore, if the Aſſymptotes

Plate 102. being O V A and O E, any Hyperbola, as *dg*, be deſcribed, the Ordinates,

F. 4, 5, 6. as A L, A L, will be to one another as the Pictures of the Object, when it is plac'd at A, or A, for theſe Ordinates are diminiſh'd, as the Diſtance O A is increas'd *.

* *La Hire Sect. Con.* Lib. 4. Prop. 2.

3167. The apparent Magnitude of the ſame Line A B, ſeen through a Glaſs,

Plate 102. is as the Angle D O V; which itſelf, by reaſon of the ſmall Line V D *,

Fig. 1, 2, 3. follows the Ratio of the Angle V *o* D, that is, of A *o* B, under which the

* 3158. Object would be ſeen, if the Eye were at *o*. Therefore an Hyperbola

Plate 102. D G being deſcrib'd at Pleaſure, it's Aſſymptotes being *o* V A and *o e*,

Fig. 4, 5, 6. it's Ordinates A *l*, A *l*, are alter'd as you recede from *o*, as the Picture in the Eye, when the Object is transfer'd with the Ordinate, and is ſeen through the Glaſs; as follows from the foregoing Demonſtration †.

† 3166.

3168. Both the Hyperbolas may be deſcrib'd at Pleaſure, as has been ſaid; but if we would make uſe of theſe together in ſuch Manner, that there may be the ſame Ratio between A L and it's Correſpondent A *l*, of the other Hyperbola, which, in that Poſition of the Object, is between the apparent Magnitude to the naked Eye, and this through the Glaſs, we muſt deſcribe the Hyperbolas in ſuch Manner, that both the Ordinates at V may

V may be equal, as V *d*, V D; becauſe, if the Object be in this Point, both the Pictures are equal *. * 3147. 3169.

When, the Lenſe being convex, the Eye is remov'd from the Lenſe, beyond the Focus of parallel Rays proceeding from a contrary Part, the Point *o* falls at the oppoſite Side of the Lenſe; then if the Object be at *o*, the Increaſe of the Picture is infinite. If the Object be then remov'd further from the Eye, the oppoſite Section *g h* is of uſe; for this is the Continuation of the Hyperbola, and it demonſtrates by it's Poſition, that the Poſition of the Picture in this Point is alter'd, that is, that the Objects appear inverted. Pl. 102. Fig. 25.

When O F exceeds F V, the Curve *g h* cuts *d g*, theſe two being continued. We diſcover the Interſection, if to theſe two O F — F V and O V, there be ſought a third Proportional, for this will determine in the Axis O A, the Diſtance between the Point O and that, to which the equal Ordinates of the Curves *g h*, *d g*, correſpond. 3170.

CHAP. XII.

Of Microſcopes and Teleſcopes.

WE have already ſhewn the Uſe of ſpherical Glaſſes, in correcting the Faults of the Eyes of old Men, and ſuch as are ſhort-ſighted *. We ſhall now conſider how they ſerve in the Diſcovery of the leaſt Objects, and bringing the moſt diſtant, as it were, to the Eye. 3171. * 3139 3144.

We have already ſaid that convex Glaſſes magnify the Objects †; which Magnifying depends upon the Refraction of the Rays, as they go through the convex Lenſe; whence it follows, that it is augmented, if, under the ſame Circumſtances, the Refraction be increaſed; and this Effect will be obtain'd, by increaſing the Convexity of the Lenſe; which will be the more convex as the Surfaces bounding it are Portions of a leſs ſphere; which can only be had in ſmall Glaſſes. 3172. † 3133.

DEFINITION I.

Such *ſmall Lenſes are call'd Microſcopes.* 3173.

Small Objects are vaſtly magnified by a Microſcope, by Means of which, Things that are inviſible to the naked Eye, may be ſeen very diſtinctly. 3174.

DEFINITION

DEFINITION 2.

3175. *The Space ſeen through the Microſcope, that is, the Circle in which Objects are viſible through the Microſcope, is call'd the Field of the Microſcope.*

EXPERIMENT 1.

3176. If the ſmall Object A E be view'd through the Microſcope V,
Pl.103.F.1. it will appear magnified at *a e* *.

*3131.3133. But we ſee Objects through a Glaſs moſt diſtinctly, when we
3177. bring the Eye as near to it as poſſible, and the Object is placed at a juſt Diſtance; which, in the Uſe of ſmall Lenſes, is entirely neceſſary, otherwiſe the Field vaniſhes.

3178. Objects ſeen through ſuch Glaſſes appear immenſely magnified, yet the Picture has the ſame Magnitude in the Bottom of the Eye,
* 3147. the Lenſe being plac'd, or remov'd *; the Amplification in this Caſe is to be attributed only to the Removal of the Confuſion. Let us ſuppoſe a Man, who ſees Objects moſt diſtinctly at the Diſtance of ſeven Inches, let him ſee a ſmall Grain of Sand, plac'd at this Diſtance from his Eye, the Picture in the Bottom of his Eye will be very ſmall; let him bring the Grain of Sand ſo near as to reduce it's Diſtance to a hundredth Part, and the Diameter of the
* 3153. Picture will be a hundred times as great *; the Viſion is confuſed, or rather, nothing at all is ſeen plainly, a Lenſe of due Convexity being plac'd between, the Object is ſeen diſtinctly; but as nothing of this happens to the naked Eye, we compare the Magnitude of the Object through the Lenſe with the greateſt, that we perceive with the naked Eyes.

3179. When very ſmall Objects, or the very ſmall Parts of Objects, are examin'd, theſe ſingle Microſcopes are to be preferr'd to others; but the Field is very ſmall, and the ſmalleſt Lenſes are hardly of any Uſe, except to thoſe, who by Uſe have acquir'd the Method of managing both Glaſſes and Objects.

3180. There are alſo Microſcopes made up of two, or three Lenſes, in which the Field is greater than in the ſingle ones, and the Amplification is greater. I ſhall ſhew the Foundation of them.

3181. Let there be a ſmall Lenſe V, very convex, and let there be an
Pl.103.F.2. Object A E at ſuch a Diſtance from it, that all the Points of it
* 3057.3011. may have their Focus behind the Glaſs *; bring the Object ſo near,
† 3011. that the Foci may be remov'd to *a e* †; there will be there a Re-
‡ 3058. preſentation of the Object, very much magnified, which will be ſenſible, if it be receiv'd upon a white Plane ‡.

EXPERIMENT 2.

This Experiment may be well made, by uſing the Tube of the Microſcope, in which tranſparent Objects, in an horizontal Poſition, may be ſtrongly illuminated by the Sun's Rays, reflected by a ſmall concave Mirror; which Microſcopes are very common in *England*, and now in theſe Parts alſo. The Wing of a Fly is plac'd in ſuch Manner, as it ſhould to be ſeen through the Microſcope, and it is ſtrongly enlighten'd; then all the Lenſes being taken out of the Tube, one only ſmall one of thoſe, which don't magnify very much, is join'd to it, at the lower End, and a Diaphragm of thin Paper, is fitted in the Middle of the Tube; the Eye being now applied to the upper Aperture of the Tube itſelf, the Picture of the ſaid Object is ſeen on the Paper; but the Tube is raiſed or depreſs'd, till the Repreſentation is diſtinct, which though it falls on the oppoſite Surface of the Paper, yet appears vivid enough. 3182.

All the Points of this Repreſentation, which we ſuppoſe to be exhibited at *a e*, are radiant Points, and viſible *, if the Paper be remov'd. The Rays proceeding from theſe are tranſmitted through a ſecond Lenſe O O, and enter the Eye, as if they proceeded from Points at a greater Diſtance between *a* and *e* †; that is, the Rays proceeding from the Object A E, after the Refraction through the two Glaſſes V and O O, enter the Eye, as if they proceeded from the Object *a e*. 3183. Plate 103. Fig. 2. * 3121. 3137. † 3131.

Therefore through ſuch *a compound Microſcope the Object appears inverted, and much more magnified than through the ſingle Microſcope.* For the Line A E through the ſingle Microſcope V, applied to the Eye, would be ſeen under the Angle oppoſite to the Vertex of *a* V *e*, and is equal to it; but now the ſame Object is ſeen under the Angle O *d* O, which is to the firſt, as the Diſtance between the Glaſſes V and O O to the Diſtance between this laſt and the Eye *. 3184. * 3153.

DEFINITION 3 and 4.

In this Microſcope the ſmalleſt Lenſe, which is next to an Object, is called the Object Glaſs, and the other the Eye Glaſs. 3185.

DEFINITION 5.

The Part of the Surface of the Object Glaſs, which is not cover'd, that is, through which the Rays, proceeding from an Object, paſs, is called the Aperture of the Microſcope. 3186.

The

3187. The Eye Glaſs muſt not be too ſmall: For the Points of the Repreſentation *a e*, although they be radiant Points, do not emit Light every way; the Rays which paſs through the Object Glaſs do only interſect one another in the ſeveral Points of the Repreſentation *a e*; which Repreſentation therefore will not be viſible, unleſs the Rays which go through the Object Glaſs do alſo go through
3188. the Eye Glaſs; therefore *the Field depends upon the Magnitude of this Lenſe.*

3189. *The Eye* alſo *muſt be* ſo *plac'd*, that all the Rays which come to the Eye Glaſs, and go through it, may come to the Eye; and this is done by placing the Eye *at* d, *the Point in which all the Rays that come from the Center of the Object Glaſs, are collected beyond the Eye Glaſs.*

3190. The Amplification may be further increaſed, by adding a ſecond
* 3012. Eye Glaſs; this is plac'd in the Angle O *d* O, as *o o*, and the Rays O *d*, O *d*, converge more *, and meet at *n*, where the Eye muſt be plac'd. The Poſition of the Object A E muſt alſo be alter'd a little, that the Object may appear diſtinctly.

3191. Objects appear bright enough through Microſcopes, becauſe they are very near the Glaſs; and ſo the ſame Number of Rays paſs through a ſmall Lenſe, as would not paſs at a greater Diſtance,
3192. unleſs through a greater Hole. Yet *often where the Objects are the moſt magnified, they muſt be enlighten'd by Rays collected through a convex Lenſe, and thrown upon them.*

The Aſtronomical Teleſcope very much reſembles the compound Microſcope.

Definition 6.

3193. *Inſtruments adapted to ſee diſtant Objects, are call'd Teleſcopes.*

3194. That which we now ſpeak of, is call'd an Aſtronomical Teleſcope, becauſe it is not fit for ſeeing Objects upon the Earth; for it repreſents them inverted; but Aſtronomers do not much regard the Situation of the Appearance of the Object.

3195. *This Teleſcope conſiſts of two convex Lenſes*, the one an Object Glaſs, which is placed next to the Objects, and the other an Eye Glaſs, placed next to the Eye. By Help of the firſt diſtant Objects
* 3058. are repreſented at a certain Diſtance behind the Lenſe *, as near Objects are in the compound Microſcope. If this Repreſentation be obſerved through an Eye Glaſs, it will appear inlarged and inverted, as has been ſaid of the Microſcope. It is plain alſo in this Caſe, as well as in the Microſcope, that *the Field depends upon*

the

the Bigneſs of the Eye Glaſs; as likewiſe that *the Place of the Eye is to be determin'd in the ſame Manner for the Teleſcope as for the Microſcope* *; *and* therefore that, by reaſon of the Length of the Teleſcope, *the Eye ought to be plac'd in the Focus of parallel Rays of the Eye Glaſs as to Senſe.* For the aſtronomical Teleſcope only differs from the compound Microſcope, that in the compound Microſcope the Lenſes are more convex, and ſo leſs fit for viewing diſtant Objects, eſpecially the Object Glaſſes. In the Microſcope the Convexity of the Object Glaſs is greater than that of the Eye Glaſs; but in the Teleſcope it is leſs. 3196. 3197. * 3189.

Teleſcopes may be as long as poſſible for obſerving the Stars; but when they are above twenty Feet long, they are of no Uſe for ſeeing Objects upon the Earth, becauſe of the conſtant trembling of the Air, which is too ſenſible in Glaſſes that magnify much. 3198.

A ſhort *aſtronomical Teleſcope will ſerve to ſee Objects upon the Earth, by adding to it two convex Lenſes*, which are alſo call'd Eye Glaſſes. 3199.

But the three Eye Glaſſes are ſimilar, and collect parallel Rays at a Diſtance double of that, at which the Eye Glaſs of the aſtronomical Teleſcope ought to collect them, the ſame Object Glaſs remaining. 3200.

Let V be an Object Glaſs, repreſenting a diſtant Object inverted at *e a*; alſo let there be three Eye Glaſſes O O, O O, O O. The firſt is ſo plac'd, that the Rays coming from the Points of the Repreſentation *e a*, may become parallel when they have paſs'd through the Lenſe *. In that Caſe the Rays which come from the middle Point of the Object Glaſs, are collected at G; the ſecond is ſo plac'd, that theſe Rays which are collected at G, where they interſect one another, and as it were come from that Point, may go out parallel *; which being ſuppoſed, the Rays coming from the Object Glaſs to *e*, and there interſecting, and forming that Point of the Repreſentation, being refracted through the firſt Glaſs, paſs through G parallel to one another; they are refracted through the ſecond Lenſe according to the Direction O *e*, and are collected at *e* *, ſo as to make it a Point of a new Repreſentation. In the ſame Manner the Point *a* of the firſt Repreſentation will anſwer to the Point *a* of the ſecond; and ſince this is true concerning the intermediate Points, the Repreſentation of the Object will be erect at *a e*. 3201. Pl. 103. Fig. 3. * 3011. * 3011. * 3010.

EXPERIMENT 3.

3202. The two Boards T, T, furniſh'd with Glaſſes *, which collect
Plate 103. parallel Rays at the Diſtance of about five Inches, are mov'd upon
Fig. 4. a Table between two Rulers, in ſuch Manner, that the Axes of both
* 2772. Lenſes may be in the ſame Line, in which the Hole alſo is, through which only the Light enters into the Chamber, and in which the Object Glaſs is fix'd, which is contain'd in the ſhort Tube A B, that the ſide Light may be excluded.

The Object Glaſs is ſuch, that it may repreſent diſtant Objects inverted at F, at a Diſtance of about three Feet from A, which Repreſentation is ſeen, if the Rays be intercepted by a white
* 3058. Plane *. The firſt Eye Glaſs is at a Diſtance of five Inches from F, from which the ſecond Lenſe is ſix Inches diſtant; at *f*, at a Diſtance of five Inches from it, there is an erect Repreſentation of the ſame Objects, which is alſo ſenſible by putting a white Plane between.

Plate 103. The Repreſentation *a e* is obſerv'd through the third Eye Glaſs;
Fig. 3. the Eye is plac'd at *d*, in which the parallel Rays *a* O, *e* O are
3203. collected; then we demonſtrate that *the Object appears amplified, nearer, and erect*; for it is ſeen under the Angle O A O, whilſt it would appear under a ſmall Angle to the naked Eyes, namely, that, which is oppoſite to the Vertex of the Angle *e* V *a*.

3204. The Object appears nearer alſo; not only becauſe the Rays go into the Eye, as if they proceeded from an Object *a e* not very remote, but chiefly, becauſe, by reaſon of the Amplification, we diminiſh the Diſtance in the Imagination.

EXPERIMENT 4.

3205. Things being given as in the laſt Experiment; a third Board S
Plate 103. is plac'd at the Diſtance of ten Inches from the ſecond Eye Glaſs,
Fig. 4. furniſh'd with a like Glaſs; and a fourth Board D, in the Middle of which is a Hole *d*, is plac'd in the ſame Line with all thoſe, and the Diſtance between S and D is about five Inches. Now if the Eye be applied to the Hole *d*, the Object, as has been ſaid, will appear erect, magnified, and near. If the Board D be diſplac'd, that is, be brought nearer or remov'd farther off, the Field of the Teleſcope is diminiſh'd; becauſe there is but one Situation of the Eye, in which all the Rays that paſs through the Eye Glaſſes can come to the Eye.

We

We are to take Notice that the Eye Glaſſes, made uſe of here, are not convex enough in reſpect of the Object Glaſs V; but they are beſt for making the third Experiment. 3206.

We determine the Amplification of the Object in this Teleſcope, by conſidering the Increaſe of the Picture of the Line of any Object, and the Picture is to the naked Eye, to the ſame, when the Teleſcope is uſed, whether one Eye Glaſs be uſed, or three equal ones, as the Diſtance, at which the Eye Glaſs collects parallel Rays, is to that, which is between the Object Glaſs and the Eye Glaſs next to it; for ſo are the Angles under which we ſee the ſame Line with the naked Eyes and through the Teleſcope; for the firſt is vertical to O V O, and the ſecond is O *d* O, as has been ſaid above. 3207.

All the Points of the Object do alſo *appear more enlighten'd:* For the Rays which, coming from any Point of the ſeveral Points of the Object Glaſs, do interſect one another in a Point of the Repreſentation, by Reaſon of the ſmall Diſtance of the Eye Glaſs from that Repreſentation, are but little diſpers'd before they come to the Eye; ſo that they all go into it. And therefore *the Illumination, given by the Teleſcope, is to that which is given by the naked Eye, as the Surface of the Aperture of the Object Glaſs, through which the Rays paſs, to the Surface of the Pupil* *. 3208. * 3123.

One may alſo *with two Lenſes make Teleſcopes, which ſhall ſhew Objects erect, enlighten'd, and magnified.* Theſe muſt be ſhorter; for if they be above one Foot long, they become almoſt uſeleſs. 3209.

Let V be an Object Glaſs; the inverted Repreſentation of a diſtant Object will be at *e a* *: The Rays are ſo intercepted by the concave Lenſe O O, that ſuch of them, as come from the Center of the Lenſe V, are inflected as if they proceeded from the Point *f* ‡; by the ſame Refraction the Rays, which concur'd at *a*, become diverging †, having their imaginary Focus at *a*; which alſo happens in reſpect to all the Points of the Repreſentation *e a*, and inſtead of it, you have an imaginary Repreſentation which is erect at *a e*; that is, the Rays enter the Eye as if they came from the Object plac'd at *a e*. 3210. Plate 103. F. 5. * 3058. ‡ 3021. † 3022.

The Rays, in all reſpects, go out diverging from the Eye Glaſs; and therefore *the Eye muſt be brought as near as poſſible to the Eye Glaſs.* 3211.

The Field in this Teleſcope depends upon the Magnitude of the Pupil; the Magnitude of the Object Glaſs muſt alſo be conſider'd; for often, in a ſhort Teleſcope, furniſh'd with a large Object Glaſs, the Rays, which come from a Point of an Object obliquely 3212.

ly to the Center of the Lenſe, don't reach the Pupil, whilſt the other Rays, proceeding from the ſame Point, which paſs through the Lenſe near the Circumference, go into the Eye.

3213. The general Theory of Microſcopes and Teleſcopes being explain'd, I ſhall add ſomething concerning the Perfection of theſe Inſtruments; I ſhall ſpeak chiefly of Teleſcopes, moſt of which may be applied to Microſcopes.

3214. The Uſe of an Object Glaſs, is to make a Repreſentation of a viſible Object, which we obſerve through an Eye Glaſs: The greater this Repreſentation is, the more diſtinctly the ſmall Parts of an Object may be ſeen. But the Magnitude of this Image, as long as we conſider the ſame Object, follows the Proportion of the Diſtance,
* 3164. at which it is from the Lenſe *. In an Object at a great Diſtance, ſuch as we now conſider, the Rays, proceeding from any Point,
3215. are Parallel to Senſe, and the Image is remov'd to *the Diſtance, at which the Object Glaſs collects parallel Rays; we call* this *the Length of the Teleſcope.*

3216. *The firſt thing* therefore *requir'd to the Perfection of Teleſcopes is, that they be long*, yet we muſt have regard to what has been ob-
* 3198. ſerved above of this Length *.

3217. The ſaid Image muſt be inlarg'd by Help of an Eye Glaſs as much as poſſible, that the Picture of the Object in the Eye may be as great as poſſible; but all the Light, whereby the Image is made,
3218. always goes into the Eye; therefore, *when the Picture is inlarg'd*, when the Light is not increas'd, *the Picture is darken'd, in the Ratio of it's Increaſe*; for the ſame Light is ſpread more.

3219. Whence it follows that the Light, whereby the Image is made, muſt be firſt increaſed as much as poſſible, and then the Eye Glaſs muſt be ſo convex, that the Amplification may be as great as poſſible, the Clearneſs remaining.

The Light that tends to all the Points of the Image, paſſes through all the Points of the Aperture of the Object Glaſs; and therefore
3220. *the Illumination of the Image is proportional to the Surface of this Aperture.*

3221. But this Aperture is circumſcrib'd in narrow Bounds for two Reaſons. The Rays proceeding from a Point, are collected into one Point only, when they are a little diſpers'd, for otherwiſe the Repreſentation of the Point is a Spot; as follows from what was
* 2895. ſaid elſewhere *.

But the Diſperſion of the Rays from this Cauſe is neglected; becauſe the Spots, that make the Image, if they do not increaſe beyond

yond a certain Magnitude, are not noxious; but before they come to that Magnitude, by dilating the Aperture, the Image is already confuſed for another Reaſon; wherefore we only conſider the ſecond Cauſe of the Diſperſion of the Rays, proceeding from the ſame Point.

Every Ray is ſubject to this Law of Refraction, which I ſhall explain more fully in the fourth Part of this Book; for a Ray is ſo divided, and diſperſed, when bent by Refraction, as to fill the Plane of the Angle, which is in the Ratio of the Bending of the Ray, at leaſt in all thoſe Caſes, of which I now ſpeak. 3222.

When the Aperture of a Teleſcope is inlarg'd, the Diſperſion of the moſt diſtant Rays increaſes, and this is eaſily ſo increaſed, that the Image will become quite confuſed; but Experience alone can teach us, how far the Spots may be increaſed, and the Image be kept diſtinct. 3223.

Now if we ſuppoſe this to be determin'd by Experience, we muſt return to the Illumination *; but in order to determine this, we muſt not ſeek ſuch an Eye Glaſs, as, when the Aperture and Length of the Teleſcope are given, extends the Picture in the Bottom of the Eye in ſuch Manner that the Clearneſs of a diſtant Object in the Teleſcope may agree with the Clearneſs of the ſame Object, brought ſo near to the naked Eye, that the Picture may have the ſame Magnitude as in the Teleſcope. But Experience has ſhewn with regard to the Day that a ſixth Part of the Light, which ſhould be thus determin'd, is ſufficient, that an Object may appear enlighten'd enough; in the Night much leſs Light is ſufficient, becauſe the Fibres of the Retina are more eaſily mov'd then, for ſo they conſtitute themſelves, when the external Light is diminiſh'd. This is the Reaſon of the Difference, mention'd above, between the Eye Glaſſes of the Teleſcopes which are uſed in the Day or in the Night *. When the Eye Glaſs is twice as acute, as has been ſhewn there, the Clearneſs is reduc'd to a fourth. 3224. * 3219. * 3200.

Therefore all that is requir'd to the Perfection of a Teleſcope, when it's Length is given, muſt be determin'd by Experiments, that is, by Trials. But theſe Trials ſuffice for one Teleſcope. For if the Length of the Teleſcope, it's Aperture, and the Diſtance at which the Eye Glaſs collects parallel Rays be given, we diſcover by Computation the Conſtruction of a Teleſcope of any other Length whatſoever, which exhibits what is viſible as diſtinct, and clear as the firſt. 3225.

3226. To avoid Confuſion we ſpoke *, as if the Trials which relate to
* 3223. the Magnitude of the Spots, mentioned in N. 3220, might be made without having regard to the Eye Glaſs; but it is not ſo, for the Confuſion depends upon the Magnitude of the Picture of this Spot, and this Picture is different according to the different Figure of the Eye Glaſs.

3227. The Trials therefore muſt be ſo made, that different Eye Glaſſes may be uſed for each of the Apertures.

3228. *Huygens* for nocturnal Obſervations determin'd an Aperture, whoſe Diameter is three Inches, when the Length of the Teleſcope is thirty Feet; and he gave an Eye Glaſs, whoſe Focus of parallel Rays is diſtant from it three Inches and a Tenth. Yet it muſt be obſerved that Object Glaſſes, except they be very well work'd, can ſcarce bear ſo great an Aperture, and that moſt Spectators require more Clearneſs; and therefore a leſs acute Eye Glaſs muſt be uſed; though *Huygens* himſelf ſometimes uſed Glaſſes more acute, than he ſhould have done according to the following Rule.

3229. If the Length be alter'd, *the Aperture muſt be alter'd in ſuch Manner, that it's Diameter may be in the ſubduplicate Ratio of the Length, and the Diſtance of the Focus of parallel Rays in the Eye Glaſs muſt be alter'd in the ſame Ratio.*

3230. When Objects are more clear, the Light, which in the Margins of the Spots did not affect the Fibres of the Retina, acts upon the Eye; and to avoid Confuſion the Aperture of the Teleſcope muſt be diminiſhed: But if this be too ſmall, the Objects do not appear exactly terminated, alſo when too much Light remains; the Cauſe of which Phenomenon is not yet ſufficiently known: In theſe Caſes, the Eye Glaſs muſt be colour'd with Smoke, to remove the too great Clearneſs.

SCHOLIUM.

The Demonſtration of the Rule delivered in N. 3229, *concerning the Determination of the Apertures, and the Eye Glaſſes of Teleſcopes.*

3231. THE Clearneſs of a Picture in the Eye, of an Object ſeen through
* 3220. a Teleſcope, is as the Aperture of the Teleſcope *; it is alſo in
† 3218. the inverſe Ratio of the Surface of the Picture itſelf †. But the Diame-
* 3214. 3215. ter of it is directly as the Diameter of the Image itſelf, which is as the
† 3152. 3165. 3197. Length of the Teleſcope *, and inverſly as the Diſtance of the Focus of
‖ 20. El. 6. the Eye Glaſs †; but the Picture itſelf is in the duplicate Ratio of the
2 El. 12. Diameter ‖. The Ratio compounded of theſe three, the two laſt being

inverted, is the duplicate direct Ratio of the Diameter of the Aperture and the Diſtance of the Focus of the Eye Glaſs, and the inverſe duplicate Ratio of the Length of the Teleſcope. Therefore in order to compare together the Clearneſs of different Teleſcopes, we muſt in each multiply the Diameter of the Aperture by the Diſtance of the Focus of the Eye Glaſs, and divide the Product by the Length of the Teleſcope, and the Quotients will be to one another in a ſubduplicate Ratio of the Clearneſs.

Now if according to the Rule the Length of the Teleſcope be as the Square of the Diameter of the Aperture, and this Diameter be as the Diſtance of the Focus of the Eye Glaſs, the Product of theſe two Quantities, will be as the ſaid Length; ſo that the ſaid Quotient will be the ſame, and the Clearneſs the ſame, for all Teleſcopes.

An Object will be ſeen equally diſtinct through different Teleſcopes, if the Magnitude of the Spot in the Eye, which exhibits the viſible Point, be the ſame *. 3232. * 3223.

Let there be the Rays B A, B A, proceeding from the ſame diſtant Point, and paſſing through the Object Glaſe V, in the Margin of the Aperture; *the Diameter of the Spot in the Image in the Teleſcope* increaſes, as the Diſperſion of theſe Rays, that is, as the Angle fAf, and as the Diſtance V F, which is the Length of the Teleſcope *. The Angle fAf *is in the Ratio of the* Angle A F V †, and this is, as to Senſe, in the direct Ratio of the Semidiameter of the Aperture V A, and the inverſe Ratio of the Diſtance V F; therefore the Ratios being join'd ff is in the direct Ratio of the Length V F, and the Semi-diameter, or whole *Diameter* *, *of the Aperture*, and laſtly the inverſe Ratio of the ſame Length; the firſt and third of theſe mutually deſtroy each other, and only the middle one remains. 3233. P. 103. F. 6. * 3215. † 3222. * 15. El. 5.

The Picture of the Diameter of the Spot in the Eye is in the direct Ratio of the Diameter of the Spot in the Image *, that is, of the Diameter of the Aperture †, and the inverſe Ratio of the Diſtance of the Focus of parallel Rays of the Eye Glaſs ‖. 3234. * 3165. † 3233. ‖ 3152. 3197. 3165.

Therefore, as theſe Ratios mutually deſtroy one another, the Picture of the Spot is not alter'd, and the Point through all the Teleſcopes, made according to the Rule, appears equally diſtinct.

BOOK

BOOK V.

PART III. Of the Reflection of Light.

CHAP. XIII.

Of the Reflection of Light, and the Law of it.

3235. WE have ſhewn that Light is reflected from opaque Bodies,
* 3057. and that every Point reflects it every Way *. The Occaſion of this is the Inequality of the Surfaces, which are made up of an innumerable Quantity of ſmall Planes, which, in all ſenſible Points, are directed every Way; which will be eaſily conceiv'd, if we imagine a Surface cover'd with an innumerable Quantity of ſmall Hemiſpheres. That this is true we deduce from the Reflection of
3236. Light from *a poliſh'd Surface*; that is, from a Surface whoſe Inequalities are taken off; which *in all it's Points reflects the Light only one Way*, which obtains in curve as well as in plane Surfaces: Nay, from Surfaces that are not at all poliſhed, the Light is moſtly reflected that Way, that it would be all reflected if they were poliſhed, as daily Experience ſhews.

3237. Let A C be a Ray of Light coming obliquely upon a plane Sur-
Plate 104. face; let C O be perpendicular to this Surface, and the Rays be
Fig. 1. reflected along C B.

DEFINITION I.

3238. *The Ray* C B *is call'd the reflected Ray.*
* 1162. The Angle O C B is call'd *the Angle of Reflection* *.
3239. *The reflected Ray is, together with the incident Ray, in the ſame Plane which is perpendicular to the reflecting Plane.*
3240. For *the Action of this Plane, by which the Light is reflected, is directed perpendicularly to the reflecting Plane*, which is ſuppoſed alike in all Points.
3241. *The Angle of Reflection is equal to the Angle of Incidence.*

EXPE-

Fig. 1.

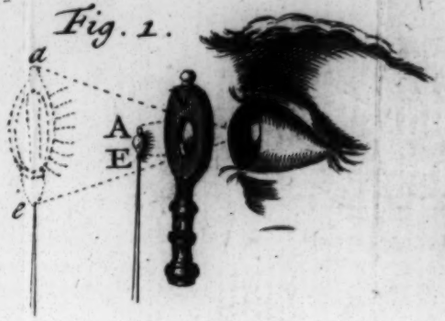
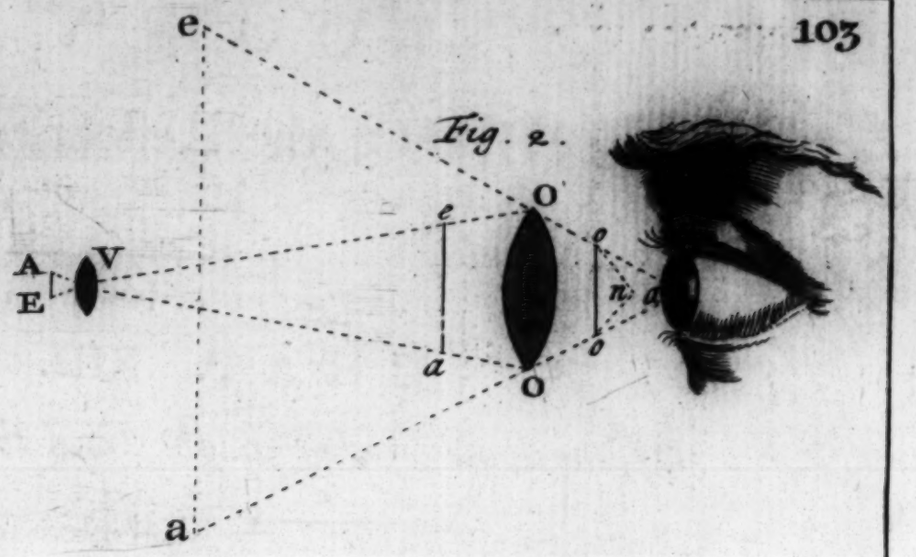


Fig. 2.



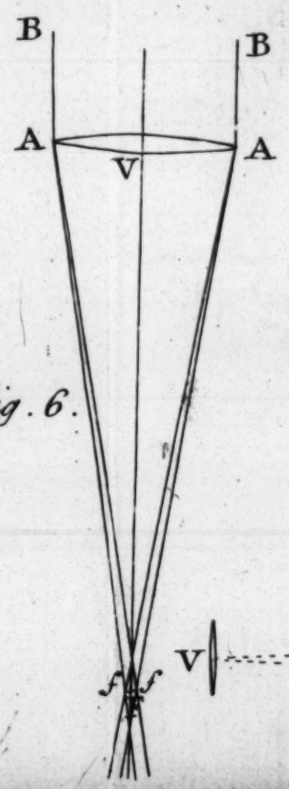


Fig. 6.

Fig. 5.

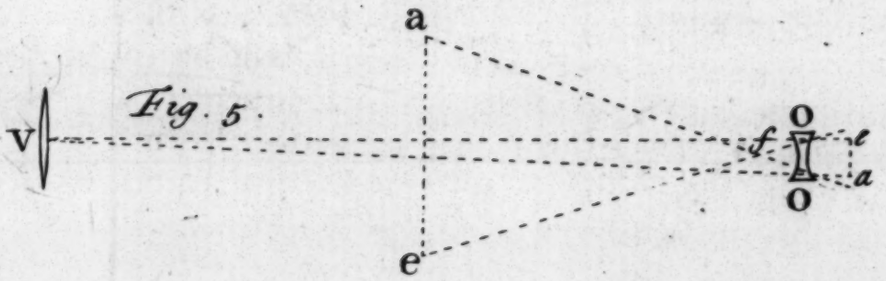
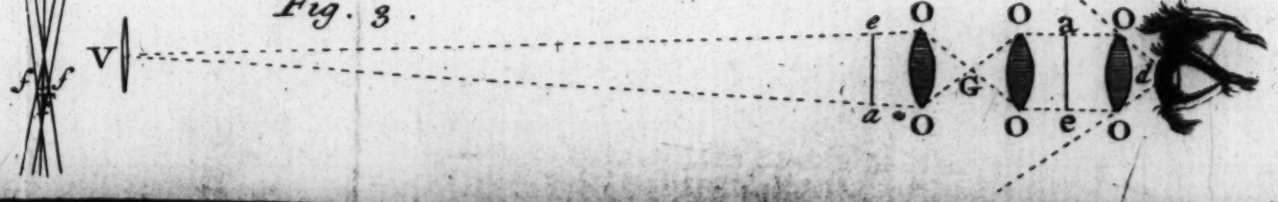
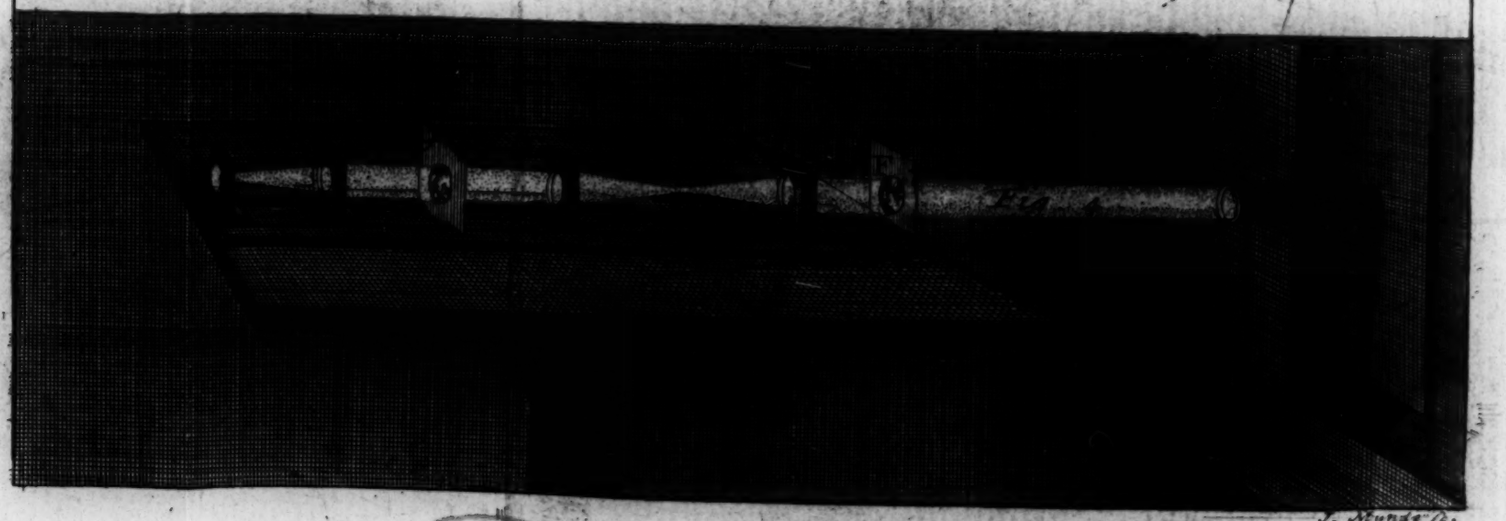


Fig. 3.





J. Meyndert fc.



EXPERIMENT I.

Let there be in the Dark the plane Mirror S, which is ſupported by a Stand in ſuch Manner, that it may be plac'd as you pleaſe *; through a Hole in the metallic Plate L, which is fix'd in a Window, a Ray of the Sun, of the Diameter of about a Quarter of an Inch, is let into a Chamber; the Mirror is ſo plac'd, that the Ray may paſs through a cylindric oblique Cavity, (whoſe Diameter is equal to that of the Ray,) in the Board T: If this be tranſpos'd, the reflected Ray will paſs through the ſame Cavity. This holds good whatever the Inclination of the Cavity be, as may be demonſtrated by uſing different Boards. 3242. Plate 104. Fig. 2. * 2735.

By which Experiment is alſo manifeſt, what was ſaid in N. 3235, of the Surfaces of Bodies. 3243.

If the reflected Ray becomes the incident Ray; that is, if the Light comes along the Line B C, it will return in the Line C A, that is, *the firſt that was the incident Ray will become the reflected Ray*; as appears from the Equality of the Angles B C O, O C A. 3244. Plate 104. Fig. 1.

From this Equality of the Angles of Incidence and Reflexion, we farther deduce, that *the Light, after it has fallen upon a Body, recedes from it with the ſame Force that it came upon it.* Let the Motion along A C be reſolved into two Motions along A O and O C *, ſuppoſing A O parallel to the reflecting Plane, and O C perpendicular to it. Let A O be continued; the Motion in that Direction is not alter'd from the Action of the Plane: therefore let A O and O B be equal; if the Light recedes from the Plane with the ſame Force, with which it came upon it, the Motion occaſion'd by the Repulſion is repreſented by C O, and in that Caſe the reflected Ray goes through B *; that is, the Angle O C B is equal to the Angle O C A, which agrees with the Experiment. 3245. * 1155. * 360.

As to the Reflexion of Light, it is to be obſerv'd, that *Light does not run againſt the ſolid Part of Bodies, when it is reflected by them; but that it is reflected in thoſe Places, where it could very freely paſs.* I ſhall prove this by ſeveral Experiments, by which many other wonderful Properties of Reflexion are diſcover'd. 3246.

It is a common Experiment obſerv'd by every Body, that when *Light* is mov'd through any Medium; as for Example, Glaſs, Water, or Air, it does not undergo a ſenſible and regular Reflexion; but that it *is reflected* there, *where two Mediums of different Denſity are ſeparated*; ſo it is reflected in the Surface of Water or Glaſs. 3247.

Can Light in ſuch Quantity ſtrike againſt the Particles of the Mediums juſt where they are ſeparated, where as it moves along both the Mediums for a great Space, without ſtriking againſt any ſuch Particles? Is there a greater Number of ſuch Particles near the Surface than elſewhere?

3248. *Light* alſo *is more abundantly reflected in a more refracting Medium, when it comes againſt the Surface of a leſs refracting one; than when on the contrary, moving in a leſs refracting Medium, it ſtrikes againſt the Surface of a more refracting one.*

EXPERIMENT 2.

3249. Pl. 104. Fig. 3. We make uſe of the triangular Glaſs Priſm as A B, whoſe Baſes are ſtrengthen'd with Copper Plates to which Points cohere, that the Priſm may be turn'd about it's Axis.

3250. Pl. 104. Fig. 4. We put the Axes into Inciſions in the Edges of the ſmaller Sides of the Box E F. The Light enters through an Hole in the Plate L into a dark Place, and goes into the Priſm; if the Light in the Priſm makes the Angle of Incidence greater than 40 Degrees, it is wholly reflected, and none of it goes into the Air; but the Light in the Air is never wholly reflected by the Glaſs.

3251. But if the Reflexion be made by the ſtriking of Light againſt the ſolid Parts of Bodies, there muſt be more ſuch Parts in Air than in Glaſs; for if Light was reflected from the Glaſs itſelf into the Air, the Light would never come to the Separation of the Mediums; that the Light can alſo go out of Glaſs in the very Places, where it is reflected, is prov'd by the following Experiments. Therefore near the Glaſs there muſt be ſo many Parts in the Air, that there may be no Way for the Paſſage of the Light to cauſe it to be wholly reflected into the Glaſs: yet it does appear that there are not ſuch; becauſe the Light came to the Glaſs through the Air in all Directions, and enter'd into it. Alſo in the ſame Part of the Surface, ſeparating the Glaſs and Air, the Light coming from one Side is reflected, whilſt that, which came from the oppoſite Side is tranſmitted. Which clearly proves that the Light is there reflected, where it can paſs through.

EXPERIMENT 3.

3252. Plate 104. Fig. 4. The ſame Things being given, which were in the foregoing Experiment, if the Obliquity of the Light be diminiſh'd, this will in part paſs into the Air.

Who can conceive that the Light, which paſſes out of the Glaſs into the Air, and does not ſtrike againſt ſolid Parts, ſhould, if the Obliquity be a little increaſed, all of it ſtrike againſt ſuch Parts; ſince

ſince in each Medium there is a Paſſage for it in every Direction, as has been ſaid?

EXPERIMENT 4.

The Priſm being plac'd, as in the laſt Experiment; turn it ſlowly, 'till it reflects all the Light, as in the ſecond Experiment *; then the Angle of Incidence of the Light, falling upon the lower Surface of the Priſm, is about 40 Degrees. The Priſm muſt be fix'd in this Poſition by Means of the Screw C. Now if Water be pour'd into the Box, at the Moment, when the Water touches the Glaſs, the Light enters into it in great Plenty. 3253. Plate 104. Fig. 4. * 3249.

The Experiment anſwers in the ſame manner, though the ſaid Angle of Incidence exceeds 40 Degrees. So that it does not exceed 60 Degrees. But it is the more ſenſible, the ſmaller this Angle betwixt the ſaid Limits is.

This Experiment does not agree with the Reflexion, ariſing from the ſtriking againſt the ſolid Parts.

In the following Part of this Book we ſhall alſo ſee, that thin Plates, which reflect Light, do tranſmit it, if they become thicker. 3254.

This Experiment alſo proves, that *the reflecting Force is the greater, the greater the Refraction in the reflecting Surface is*; for Glaſs and Air differ more in their refracting Force, than Glaſs and Water do. 3255.

From this Experiment we alſo deduce, that the *Reflexion is made from the ſame Force, by which the Rays are refracted; which in different Circumſtances produces different Effects.* 3256.

A Ray, which paſſes out of a more refracting Medium into a leſs refracting one, recedes from the Perpendicular by Means of the Attraction of that Medium *; if the Obliquity of the incident Ray be increaſed, the Obliquity of the refracted Ray is increaſed alſo, 'till at laſt this moves in the Surface itſelf, that ſeparates the Mediums. Which obtains, when the Sine of the Angle of Incidence is to the whole Sine, as the Sine of Incidence, in the firſt Medium, is to the Sine of Refraction in the ſecond; for in this Caſe the Angle of Refraction is a Right one. If the Obliquity of the incident Ray be further increaſed, it is manifeſt that the Ray cannot penetrate into the leſs refracting Medium; this is the Caſe, in which all the Light is reflected; which Reflexion depends upon the Attraction with which the Rays are refracted. 3257. * 2782.

Let E F be the Surface ſeparating the more refracting Medium X from the leſs refracting one Z; let us ſuppoſe the Space of Attraction * to be terminated by the Surfaces G H, I L; if a Ray, as A B, Plate 104. Fig. 5. * 2806.

be ſufficiently bent by the Attraction of the Medium X, ſo that, before it ſhall have paſſed through the whole Space of Attraction, the Tangent to the Curve be parallel to the Surface ſeparating the Mediums, the Curve being continued goes back; and therefore the Ray is reflected along C D, from the Attraction of the Medium, whoſe Action upon the Light overcomes the oppoſite one. This Continuation of the Curve is ſimilar, and equal to the firſt Portion, and makes the Angle of Reflexion equal to the Angle of Incidence; becauſe the Light returns along the ſame Part of the Space of Attraction, and the ſame attracting Forces act upon the Light in correſponding Points of the Portions of the Curve. Thus a Body projected, deſcribes ſimilar and equal Curves, in it's Aſcent and Deſcent.

Now as the Reflexion of the Light, in this Caſe, is plainly to be attributed to the Cauſe of Refraction, who can imagine, when the Inclination is diminiſhed, ſo that the Ray in part paſſes through,
* 10. that another Cauſe is to be ſought *?

3258. Nevertheleſs it is manifeſt that *all Reflexion does not depend upon this Attraction in the ſame manner*; for in that Caſe in which the Refraction is given, the Light is in part reflected; the Light does not indeed wholly paſs out of the leſs refracting into the more refracting Medium; for in this Caſe alſo, in which the Attraction is moſt oppoſed to the Reflexion, ſome Rays are reflected; which Effect muſt be attributed to the Repulſion, which we have alſo
* 2726. found to act where there is Attraction *.

3259. From all this it follows that the *Reflexion in every Caſe, has a Relation to the refracting Force.*

3260. Therefore *where Light paſſes without Refraction, there it is not*
* 3247. *reflected* *; *but where the Refraction is greateſt, there alſo the Reflexi-*
† 3255. *on is ſtronger* †; the Light being ſuppoſed in the Air, the Surface of the Glaſs reflects more ſtrongly, than that of the Water; and the Surface of Diamond ſtill ſtronger. The Glaſs and Diamond being immerged in Water, in the Separation of theſe Bodies by the Water the refracting Force is leſs, than the Air, and of the ſame Bodies: Theſe Bodies alſo reflect Light leſs ſtrongly in Water, than in Air. If Light moves in Glaſs, and ſtrikes againſt the Surface of Air, it is all reflected at a leſs Obliquity, than when it ſtrikes againſt
* 3253. the Surface of Water *.

From what has been hitherto explained concerning Reflexion we infer, that it is not made in the Surface of Bodies; but that
3261. *Light is reflected at a certain Diſtance from Bodies*, in the ſame

manner as the refracting Force acts at a certain Diſtance from a Body; which Propoſition we can alſo deduce from the Reflexion of Light from Surfaces made ſmooth by Art; for it has been obſerv'd, that *Bodies, that are made ſmooth by Art, reflect Light regularly,* 3262.
though there are innumerable Scratches in their Surfaces: For they are poliſh'd by the rubbing of Powders, and how ſmall ſoever theſe Particles are, they leave large Scratches on the Surface with regard to Light; whence the Reflexion in the Surface muſt neceſſarily be irregular; but if we conceive the Reflexion to be made at a ſmall Diſtance from the Surface, the Irregularities are diminiſh'd, and almoſt wholly taken away; as is eaſily perceiv'd if we conſider the Matter.

CHAP. XIV.

Of plane Mirrors.

LET *bc* be the Surface of a plane Mirror; R the Radiant 3263.
Point. *Let the Plane of the Mirror be continued, and let* Plate 104.
down to it the Perpendicular RC *from the Radiant* R; *if this be* Fig. 6.
continued, and C*r be equal to* CR, *r will be the Point of Diſperſion of the reflected Rays coming from* R.

Let R*b* be the incident Ray; *bf* the reflected Ray; let this be 3264.
continued beyond the Speculum; by reaſon of the Angles of Incidence and Reflexion being equal to one another *, the Angles * 3241.
R*b*C, *f b d*, their Complements are alſo equal; to this the oppoſite vertical Angle *r b* C is equal ‡: The right angled Triangles ‡‡ 15. El. 1.
R*b*C, *r b*C have the common Side C*b*, and the Angles C*br*, C*b*R equal; therefore they agree in every Thing, and CR and C*r* are equal to one another *; which Demonſtration may be ap- * 26. El. 1.
plied to all other Rays, proceeding from R, in what Plane ſoever perpendicular to the Plane of the Mirror, they be conceiv'd. Therefore whereſoever a Spectator be, if the reflected Rays come to him, they will enter his Eyes, as if they came from *r*; and the Point R will appear in this Point †; but *the Appearance of this Point* 3265.
has the ſame Poſition with regard to the Mirror, behind it, which the * 3122.
Radiant Point itſelf has before it.

Which if it be applied to all Points of the Object, it will appear, that *the Object appears behind the Mirror in that Poſition, which it* 3266.
really has before it.

3267. If there be many Mirrors, and the Light reflected from one, ſtrikes againſt another, in order to diſcover the Place in which the Object appears, we have the Image in the firſt Mirror for an Object with regard to the ſecond, and ſo of the others. This Rule alone is ſufficient to explain all the Phenomena of plain Mirrors, howſoever combin'd.

CHAP. XV.

Of convex ſpherical Mirrors.

3268. EVERY ſpherical Surface may be conſidered as made up of
* 2917. innumerable ſmall Planes *; and a Plane touching the Sphere in any Point, is, as it were, a Continuation of ſuch a ſmall Plane.

3269. Spherical Mirrors are either *concave*, or *convex*.
The former are made of a concave poliſhed Portion of a Sphere.
And the latter of parts of Spheres poliſhed on the outſide.

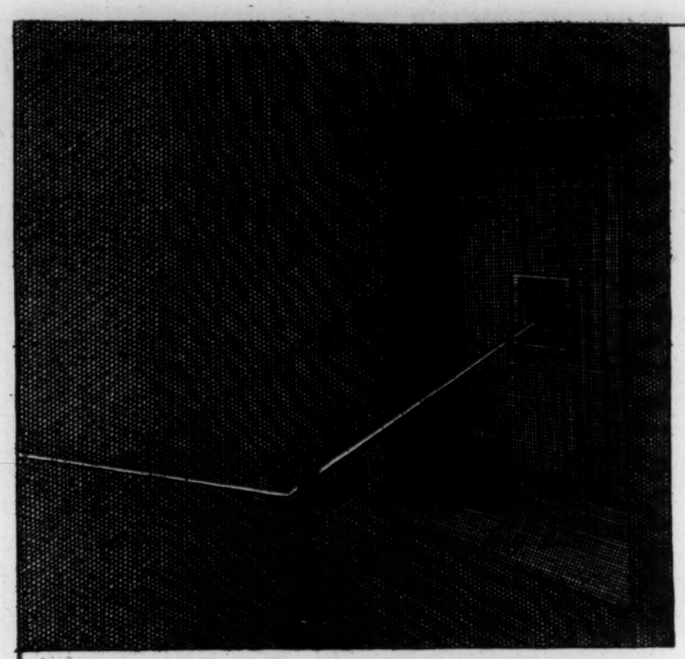
3270. *A Ray ſtriking upon any ſpherical Mirror, together with it's reflected Ray, is in the ſame Plane, which Plane being continued, paſſes*
* 3239. *through the Center of the Sphere* *, for ſuch a Plane is perpendicular to the Surface of the Sphere.

3271. *A Line which is drawn through the Center of the Sphere and Point of Incidence, being continued, makes equal Angles with the incident and*
* 3241. *reflected Rays* *, for this is perpendicular to the Surface, and theſe
3272. are the Angles of Incidence and Reflexion: Therefore *the Ray which paſſes through the Center, or which being continued would paſs through the Center, when reflected, returns upon it ſelf.*

3273. Let R be the radiant Point; G *a* G is the convex Speculum;
Plate 105. C the Center of the Sphere; and G D a part of a Section of the
Fig. 1. Sphere continued: Let R *a*, R *b*, R *c*, R *d*, be incident Rays,
* 3272. when reflected they will be *a* R, *b n*, *c m*, *d l* *.

3274. *If from the Radiant Point* R, *a Tangent be drawn to the Mirror*, the reflected Ray will be the Continuation of the incident Ray, or rather *the Reflexion of the Rays is terminated in the Point of Contact.*

3275. *If the Rays l d, i m, n b*, R *a*, *which are reflected from the convex Mirror, be continued out*, with all the intermediate ones, *their Interſections will form the Curve* F G, which all thoſe Rays touch, and the adjacent Rays interſect one another in the Circumference of the Curve itſelf; ſo that they always enter the Eye as if they came from ſome Point of the Periphery; *in which* therefore *the Image of the Point*



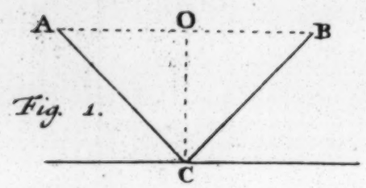


Fig. 1.

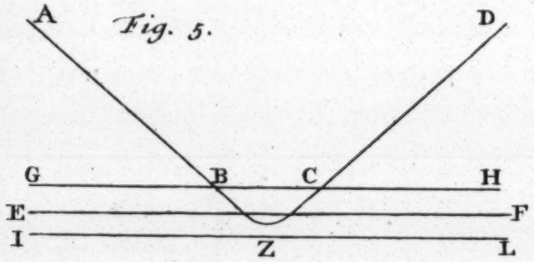
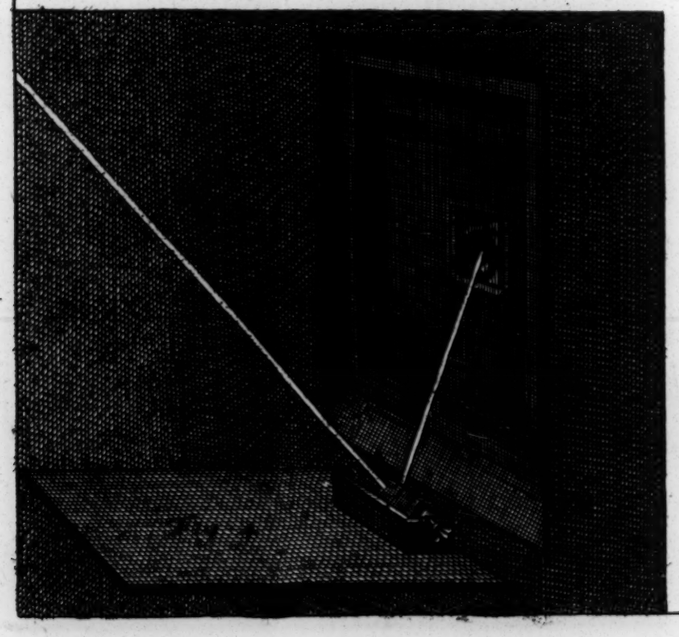


Fig. 5.



Fig. 3.



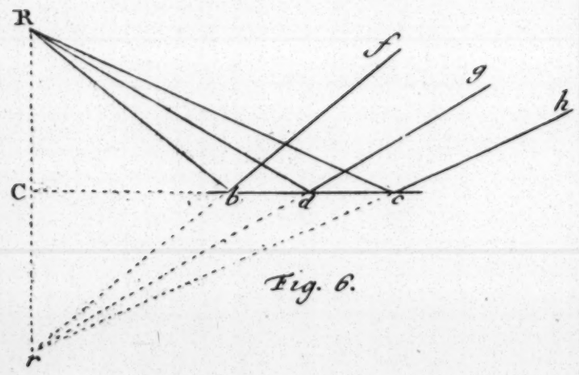


Fig. 6.

J. Myn. desc.

Point does always *appear* *, *as long as* the reflected Rays can come to *the Eye, and the Eye be moved in the Plane going through the Center of the Sphere.* But *when the Eye is removed out of that Plane, the radiant Point appears in ſome other Curve*, becauſe there are ſuch Curves in every Plane, which may be conceiv'd to paſs through the Line R C. * 3122. 3276.

If the Eye be in the Line *d l*, the Point *f* of the Curve, from which the Rays ſeem to proceed, is determin'd by this Proportion: The incident Ray R *d* is continued to D; the Point *e* is mark'd in ſuch manner that *d e* may be equal to a Quarter of the Cord *d* D; and R *e* is to R *d*, as *d e* is to *d f*. Which we ſhall demonſtrate in the following Scholium. 3277.

In the ſame Scholium we ſhall alſo conſider the Thing more accurately, and we ſhall ſee that all, which we have delivered concerning the Tranſlation of viſible Points through the Curves mentioned, as likewiſe that which I ſhall preſently add, belongs to other Curves; but as the Conſideration of theſe ſecond Curves is intricate, and as our Mind rarely refers the Point itſelf of the Object to the viſible Point *, it is ſufficient to conſider the firſt Curves, upon which the ſecond depend, as will be ſeen in the ſaid Scholium. 3278. * 3124.

If the Rays be direct, that is, if R *a* be given amongſt them, which being continued would paſs through C, R E and R F are in the ſame Line *, and *a* F is leſs than *a* E which is equal to a Quarter of the Diameter. 3279. * 3272.

The Point F *coincides with* E *when* R *is remov'd in infinitum*; for then R *a*, R E, muſt be look'd upon as equal. 3280.

The Point F *is, of all the Points of the Curve, the moſt diſtant from the Surface of the Speculum.* 3281.

Now any radiant Points being given, all the Curves of theſe Points, and indeed the whole Curves are within the Sphere; and therefore *all the Objects appear behind the Surface of the Speculum.* 3282.

If the Point R be mov'd about the Speculum, the whole Curve G F G is carried with the ſame Motion; therefore as the Radiant aſcends, the Repreſentation aſcends alſo, and the contrary; and *the Objects appear erect.* 3283. 3284.

How great ſoever the Space taken up by the Objects be, the Appearances are incloſed in a ſtrait Line *. Whence it follows that *the Objects appear diminiſhed.* * 3280. 3285.

If the Eye be mov'd, the Appearance of the Object is alſo mov'd, and it's Figure chang'd: For all the Points are mov'd in their own Curves, and that unequally, according to the different Situation of the 3286.

the Eye in reſpect of each Curve; whence of Neceſſity the Figure muſt be chang'd.

EXPERIMENT.

3287. Plate 105. Fig. 2. If any one ſees his Face in a ſpherical convex Mirror, ſtanding at A, he will ſee his Face erect at *a*, diminiſh'd and unlike; by the Motion of the Eye one may obſerve the other things mentioned, in reſpect to fix'd Objects.

SCHOLIUM I.

The Demonſtration of the Rule deliver'd in N. 3277, *whereby the Appearance of a Point is determin'd.*

3288. Pl. 105. F. 3. LET there be the incident Rays RA, R*a*, which we conceive to be continued, as far as D, *d*; and AD is = 4AE. And let there be the reflected Rays AI, *ai*, which being continued backwards to AB, *ab*, mutually interſect one another at F. The Angle AR*a* being ſuppoſed very ſmall, F is ſought.

* 36. El. 3. RA, R*a* : : R*d*, RD*.

16. El. 6. Therefore the Triangles RA*a*, RD*d* are ſimilar †; and

† 16. El. 6. D*d*, A*a* : : RD, R*a* or RA;

for theſe are taken as equal, by reaſon of the ſmall Angle DR*d*.

3289. By Compoſ. D*d* + A*a*, A*a* : : RD + RA, RA.

* 35. El. 3. In the ſame manner FA, F*a* : : F*b*, FB*;

16. El. 6. And the Triangles FA*a*, FB*b* are ſimilar †; and

† 15. El. 1. B*b*, A*a* : : FB, F*a* or FA.

6. El. 6. By Diviſ. B*b* — A*a*, A*a* : : FB — FA, FA.

3290. By reaſon that the Angles of Reflexion are equal to the Angles of

3291. Incidence *, DAC, BAC are alſo equal, as alſo *da*C and *ba*C †;

* 3271. wherefore the Chords AD, AB, and *ad*, *ab* are equal; therefore

† 15. El. 1. AD — *ad* = AB — *ab*; that is, A*a* + D*d* = B*b* — A*a*; and the firſt

* 3289. 3290. Ratios of the Proportions deliver'd above * agree.

Therefore RD + RA, RA : : FB — FA, FA.

By Compoſ. RD + 2RA, RA : : FB, FA.

By Comp. and Altern. RD + 3RA, AB : : RA, FA.

But RD + 3RA = 4RA + 4AE = 4RE, and AB = AD = 4AE;

Therefore 4RE, 4AE : : RE, AE : : RA, FA.

According to the Rule, which is deliver'd in the ſaid N. 3277.

3292. If we conceive the Lines RA, R*a* to revolve about RC, the Angles ARC, *a*RC remaining, the Point F will deſcribe a Circle; and it is manifeſt that only thoſe Rays, which are in the Plane of the Figure, meet at F: If, therefore, the Rays proceeding from R make a Cone or Pyramid, the Rays, how little ſoever diſperſed, don't meet in one Point, but by

by mutual Interſections make a ſmall Portion of the ſaid Circle, namely a ſmall Line perpendicular to the Plane of the Figure at F. The ſame Rays alſo paſs all along the ſmall Line L *l*, ſo that what obtain'd in the refracted Rays*, takes Place here, in the imaginary Interſections of the Rays produc'd backwards. Whence it follows, if we conſider the Thing accurately, that the Point F is not a viſible Point *; but that the ſquare Spot is to be look'd upon as ſuch, as has been mention'd above †. The Place Q of this Spot, if we conſider the Rays, which go directly through the Pupil into the Eye, is determin'd, if in the Line A L, in which the Point F is now given, the Point Q be determin'd in ſuch manner, that the Line may be divided harmonically; that is, that L A, L Q : : A F, F Q. A P being drawn through A, parallel to R C; draw through P, taken at Pleaſure P F, which cuts R C at S; L S being divided into equal Parts at *s*, the Line P*s* will determine the Point Q.

* 2901. 2987.

* 3122.

† 290.

But all this is of no Uſe in explaining Phenomena *. Therefore it is ſufficient to have explain'd what relates to the Curves, paſſing through Points as F, neglecting the ſecond Curves, which paſs through Points as Q; this we know, that the Appearances are chang'd with the Points, as F and Q, which are always chang'd together: For which reaſon, in the following Chapter I ſhall only conſider the firſt Curves. 3293.

* 3124.

When incident Rays, a little diſperſed, are direct, that is, if among theſe there be a Ray, which continued would paſs through C, the Points F, Q, and L coincide. 3294.

CHAP. XVI.

Of ſpherical concave Mirrors.

WHEN we conſider Objects, ſeen by Rays reflected from a Mirror, it is needleſs to treat ſeparately of direct and oblique Rays; becauſe, whilſt ſome few Points of an Object are ſeen by direct Rays, all the reſt are ſeen by oblique Rays. For this reaſon in the laſt Chapter I did not treat ſeparately of direct Rays; but as other Phenomena alſo are to be explain'd in this Chapter, which depend upon direct Rays, I ſhall treat of theſe firſt. 3295.

Let there be a concave Speculum B D, C is the Center of the Sphere; *let direct parallel Rays fall upon the Surface of the Mirror*, among which is C D paſſing through the Center; by Reflexion this returns upon itſelf *, and *the neighbouring Rays, being reflected converge, and meet* with it at the Focus F, the middle Point betwixt D and C. 3296. Plate 105. Fig. 4.

* 3272.

3297. Let A B be a Ray at a ſmall Diſtance from C D, draw the Semi-diameter C B; the Angle of Incidence will be A B C, to which
* 3271. the Angle of Reflexion C B F is equal *, as alſo the alternate An-
† 29. El. 1. gle B C F †; therefore B F C is an Iſoſceles Triangle, and the
‡ 6. El. 1. Sides F C and F B are equal ‡. By reaſon of the ſmall Arch B D, F D and F B do not ſenſibly differ; therefore F C and F D are equal: Which Demonſtration agrees to all the Rays at a ſmall Diſtance from C D.

3298. If the parallel Rays be at a greater Diſtance from C D, they will not meet at F; but they all meet in a ſmall Circle, whoſe Diameter depends upon the Magnitude of the Mirror.

3299. The Rays which come from any Point of the Sun, fall parallel
Plate 106. upon the Mirror; and if they be a little diſpers'd, they meet in a
Fig. 7. Point in that Ray, which paſſes through the Center of the Sphere. If D A and E B be Rays proceeding from the Extremities of the Diameter of the Sun, theſe being reflected meet at *a* and *b* with all the others, proceeding from the ſame Points of the Sun, and reflected from the Mirror. If theſe fall upon a Plane, they will give the Images of the ſaid Points at *a* and *b*, and we have the Image of the whole Sun in the ſame manner, and the Line *a b* is the Repreſentation of the Diameter.

As in this Image, a great Plenty of the Sun's Rays is collected
* 3051. in a ſmall Space, we have the ſame Effect as in *Burning Glaſſes* *;
3300. and concave Mirrors are *Burning Glaſſes*, which *for the moſt part burn Bodies more violently than Glaſſes*; becauſe they may eaſily exceed Glaſſes in Magnitude.

3301. When the Diameter of a Mirror is ſmall, for Example, not exceeding ſix Degrees, the Image of the Sun is diſtinct, and all the Rays, reflected from the Speculum, paſs through it; then the ſmall Line *a b*, which is the Diameter of the Place, where the Combuſtion is, is leſs than the hundredth part of the Diſtance A *a*, or B *b*, as will be ſeen in the firſt Scholium following.

3302. If the Mirror be inlarg'd, the Image becomes imperfect, and by this the Diameter of it is increaſed; but the Effect of the Mirror is increaſed by this Dilatation, becauſe the Number of Rays paſſing
3303. between *a* and *b* is increaſed. But it is needleſs to increaſe the Mirror in ſuch manner, that the Arch L M, which determines the Diameter of the Mirror, may exceed five Degrees; for the Mirror being ſo order'd, that *a b* may anſwer to the Center of it, none of thoſe Rays, which would ſtrike againſt the Mirror beyond M and L can come to the Image *a*, *b*, and increaſe the Effect of the Mirror,

if

if the Diameter of the Mirror ſhould exceed the ſaid Meaſure of twenty five Degrees.

Experiment 1.

Let there be a concave Speculum S made of Metal, or Glaſs, that has Quickſilver upon the back part of it. This is ſupported by two Pillars A B, A B, between which it is inclined as you pleaſe, theſe are in a tranſverſe piece of Wood *a a*, which is put upon the Stand P, and is moveable about an Axis going into the Stand itſelf. 3304. Plate 105. Fig. 5.

The Mirror is expoſed to the Sun Rays in ſuch manner that the Rays which come to the middle Point of the Mirror may be perpendicular to the Surface of it; as all the other are parallel to this, they are collected in the Image of the Sun, at a Diſtance from the Mirror equal to a Quarter of the Diameter of the Sphere, and there burn violently.

If the Diameter of the Surface of the Mirror be as in mine, about fifteen Inches, and the Focus be at the Diſtance of a Foot and half, Wood is immediately ſet on Fire, and thin Plates of Lead are melted in a ſhort Time.

If two ſuch Mirrors be placed vertically, in ſuch manner, that the Line, which paſſes through the Centers of both, may paſs through the Center of the Spheres, we may extend the Action of a burning Coal to a great Diſtance. 3305.

Let the Diſtance between the Mirror be twenty Feet, and a Burning Glaſs plac'd in the Focus of parallel Rays in the ſaid Line, let Gunpowder be placed in the Focus of the other Mirror in the ſame Line; if you make the Coal burn fiercer with a Pair of Bellows, the Gunpowder will be ſet on Fire; for by the ſecond Reflexion the Rays are collected, which after the firſt are parallel. For *when the Focus, in which the parallel Rays are collected by the concave Speculum, becomes the radiant Point, the Rays being a little diſperſed, are reflected parallel to one another* *. 3306. * 3296. 3244.

What has been ſaid † *concerning parallel Rays a little diſperſed, and direct, may alſo be apply'd to oblique Rays.* For if there be ſuch Rays D A, *d a*, theſe being reflected mutually, interſect one another at F in ſuch manner, that A F may be equal to a Quarter of the Cord A B; which follows from the Propoſition which will be preſently deliver'd *, and demonſtrated in the following Scholium. 3307. Plate 105. Fig. 6. † 3296. * 3315.

Hence we deduce a Method of repreſenting Objects in a dark Place, like that mention'd before, by making uſe of a convex Lenſe *. 3308. * 3058.

Plate 106. Fig. 1. Let there be a Hole F in a Wall; let *ab* be a concave Speculum, ſo plac'd, that the Rays paſſing through F, and which are perpendicular to the Wall, may be direct, and if they are parallel, they may after Reflexion be collected in the Center of the Hole: The Rays which being reflected from Objects mutually interſect one another in this Center, are reflected perpendicular to the
* 3306. Wall *.

Let A F be Rays proceeding from a Point of a diſtant Object, which we look upon as parallel by reaſon of the Diſtance of the Point; among theſe, that which paſſes through the Center of the
* 3306. Hole is reflected from the Mirror perpendicular to the Wall *, and together with this the reſt of the Rays proceeding from the ſame
* 3307. Point, are collected at *a*, where the Repreſentation of the Point is *. In the ſame manner the Rays along B F proceeding from another Point, are collected at *b*; which as it obtains in Reſpect to all the Points of the Object, they have all their Focuſſes; but all theſe Focuſſes, as far as can be perceived, fall upon the Surface itſelf of
* 3307. the Wall *, and there give the Picture of the Object.

Experiment 2.

3309. Plate 106. Fig. 2. In a dark Place the Window is cover'd with the white Paper A in the Middle of which is the Hole F, whoſe Diameter is ſomewhat greater than half an Inch, and which agrees to the Hole in the Window, to which various Objects illuminated by the Sun anſwer at the Diſtance of at leaſt fifty Feet; the concave Mirror S, the Diameter of whoſe Surface is fifteen Inches, and which collects parallel Rays at the Diſtance of eighteen Inches, is plac'd, at this Diſtance from the Window, in ſuch manner that a Line, paſſing through the Center of the Hole, and the Center of the Surface of the Mirror, may be perpendicular to the Plane of the Paper and the Surface of the Mirror, then the Objects are repreſented above the Paper in a Circle concentrick with the Hole, and whoſe Diameter ſcarce differs from the Diameter of the Mirror. A hollow'd truncated Cone is join'd to the Hole without the Chamber, to include the Light which does not come from the Objects to be repre-
* 3060. ſented *.

3310. Plate 107. Fig. 1. Something like this we demonſtrate with regard to near Objects. Let R be the Radiant Point, R C *a* a Ray running directly againſt the concave Mirror L M, the Center of whoſe Sphere is C; this is reflected along *a* C, and the neighbouring ones proceeding from R as R *b* meet with it at *f*, which Point, as we demonſtrate in the Scholium,

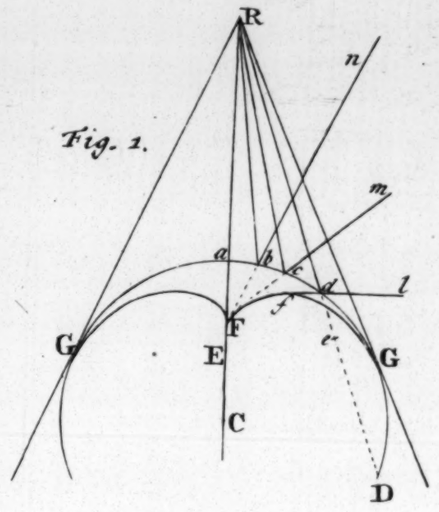


Fig. 1.

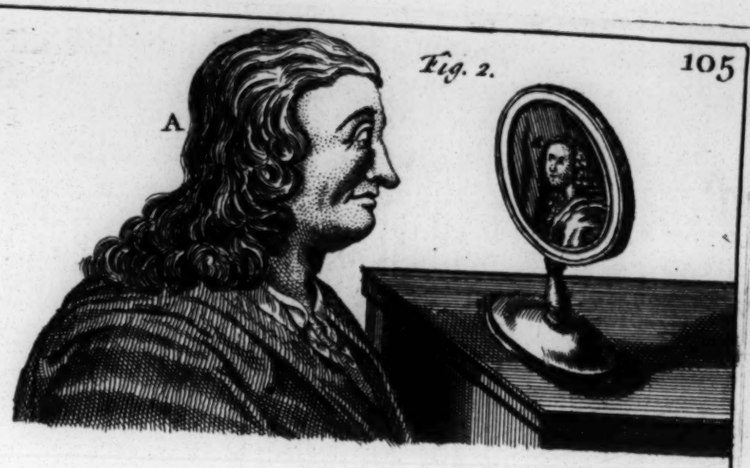


Fig. 2.

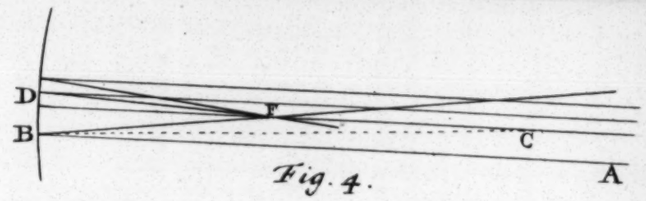


Fig. 4.

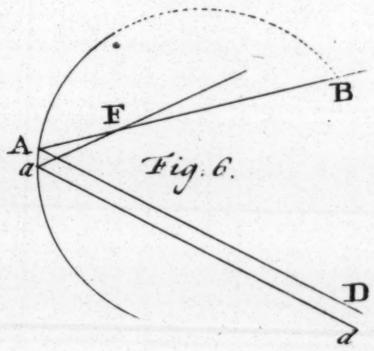


Fig. 6.

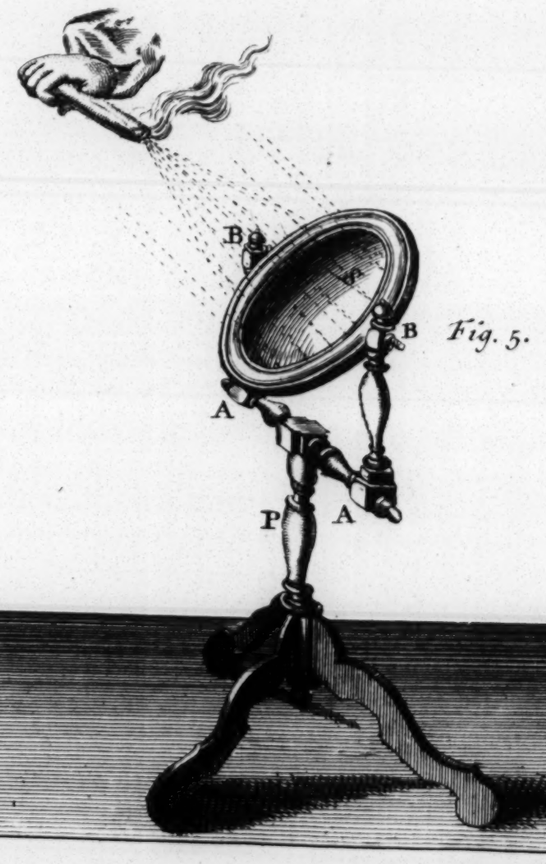


Fig. 5.

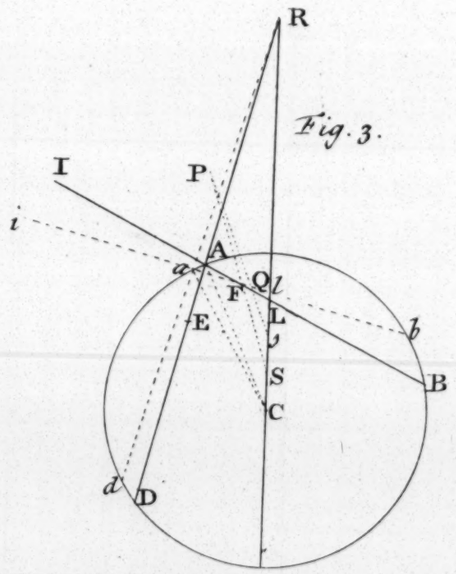


Fig. 3.

Scholium, is found by this Proportion: Let *e* be the Focus of parallel Rays *, as R*e* is to R *a*, ſo is *a e* to *a f*; if *f* becomes the Radiant, R will be the Focus, which is found in the ſame manner; for from that Proportion we deduce this, *f e* is to *f a* as *a e* is to *a* R. If there be many radiant Points, every one will have it's Focus, and by Means of them an Object may be repreſented. * 3297.

Let C be the Center of the concave Speculum M L and A B a lucid Body, which is at a leſs Diſtance from the Speculum than from the Center C, the Ray A *d*, which is perpendicular to the Speculum, is reflected along *d* A C *a*, and has it's Focus at *a*. We reaſon in the ſame manner concerning the other Points of the lucid Body, an inverſe Image of which is made at *a b*. 3311. Plate 106. Fig. 3.

Experiment 3.

The concave Speculum S being put into a vertical Poſition, let the Flame of a Candle be placed between the Center of the Sphere and the Focus of parallel Rays at F; if direct Rays coming from the Flame, being reflected from the Speculum, fall directly upon the white Plane P, placed at a juſt Diſtance beyond the Center, the Picture of the Flame will be inverted. 3312. Plate 106. Fig. 4.

The Diſtance of the Plane from the Speculum is the leſs, the greater the Diſtance of the Flame from the Speculum is *. * 3310.

If the Surface of the Speculum be ſmall, the Repreſentation is accurate, that is circular; becauſe the Rays that are a little diſperſed are collected accurately enough. If this Surface be greater, the Repreſentation of the Flame is ſurrounded with a kind of falſe Light, which is to be attributed to the more oblique Rays of which I ſhall now ſpeak more diſtinctly, for the Appearances of Objects belong to theſe chiefly. 3313.

Let there be a concave Speculum a d; C the Center of the Cavity; R *the radiant Point, at a greater Diſtance from the Speculum than the Center* C; R *a*, R *b*, R *c*, R *d*, the incident Rays, of which *the reflected Rays a* C, *b g*, *c h*, *d i*, *by mutual Interſections* with the intermediate ones, *make the Curve F f l, which they all touch*; therefore *the Point* R *appears in this Curve, and, the Eye being mov'd* in the Plane of the Curve, *the Appearance is transfer'd* along this Curve, as has been ſaid of convex Speculums *. 3314. Plate 106. Fig. 5. * 3275.

In the ſame manner alſo, as has been explained of convex Speculums, we diſcover the viſible Points; if the Eye be in the Line *d i*, along which the incident Ray R *d* is reflected, which cuts the Sphere continued at D, *d e* being taken equal to a Quarter of 3315.

of the Cord D*d*, R E will be to R*d*, as *de* to *df*, as has been ſaid
* 3377. of a convex Speculum *.

But in every one of the Planes, which may be conceived to paſs through C R, there is ſuch a Curve; they all meet in the Line
3316. *a* C R, namely at F. Therefore *at the* ſaid *Point* F *the reflected Rays are collected in the greateſt Plenty*; *which* therefore *is call'd the Focus of Rays proceeding from* R; *vice verſa* R is the Focus,
* 3244. the Radiant being ſuppoſed at F *, and theſe are the Points, ſpoken
† 3310. of above †.

In this Figure the Part of the Curve which is one Side of the Line R C is only delineated; a like Part muſt be conceived on the other Side; both are joined in the Focus of the radiant Point.

3317. *As the radiant Point recedes, the Curve approaches the Speculum.*

As the Radiant approaches, the Curve recedes from the Speculum, and is mov'd toward the Radiant itſelf. Let R be the radiant Point,
Plate 107. and D *a* D the Speculum, *d f d* is the Curve; and as the Radiant
Fig. 4. approaches towards the Center C they are contracted; but *if the*
3318. *Radiant be in the Center* itſelf, *all the reflected Rays coincide with the*
* 3272. *incident Rays* *; and the whole Curve as it were is collected in the Center.

3319. *If the Radiant* approaches ſtill nearer, ſo as to *be between the Center and the Speculum, the Curve* recedes more alſo, which then *is beyond the Center*; if D A D be the Speculum, *d* F *d* is the Curve, in which the Point F recedes moſt of all; in which all the Curves, which are conceiv'd in the different Planes, meet, and it is the Fo-
3320. cus of the radiant Point, which is at an infinite Diſtance, *when the*
Plate 107. *Diſtance of the Radiant from the Speculum is equal to a Quarter of*
Fig. 5. *the Diameter of the Sphere* *, then *the Curve is extended in infi-*
* 3297.3306. *nitum, and the two Sides,* which tend to the Focus of the radiant Point, *are ſeparated.*

3321. *If the Radiant approaches nearer, the Sides,* as *d* I, *d* I, *mutually*
Plate 107. *decline more from one another,* becauſe the Rays reflected from the
Fig. 6. Part of the Speculum *b* A *b* diverge; that is, being reflected they mutually interſect one another continued beyond the Speculum, and *make a new Curve behind tke Speculum, which alſo conſiſts of two Legs f l, f l,* theſe meet in the Line C R continued, namely, at *f*; and in receding from the Speculum are ſtretch'd out *in infinitum.*

3322. On each Side of the radiant Point there is given in the Surface a Point as *b*, which ſeparates the Rays making the Curves *f l*, *d* I, and the Ray R *b* being reflected to *b g* touches neither Curve, if it be continued *in infinitum*, although it approaches to each Curve nearer and nearer.

This

This Point *b* may eaſily be determin'd if the Chord *b* B be drawn; R *b* will be equal to a Quarter of it *, but this Part *b* R is a mean Proportional between the Part R A of any other Chord, paſſing through R, and a third Part of the remaining Portion R *a* of the ſame Chord †. 3323. * 3307. †35. El. 3.

If the whole Sphere ſhould be finiſh'd, with reſpect to the oppoſite Part of the Sphere, the Radiant would be at a Diſtance beyond the Center, and the reflected Rays would make the Curve *d* F *d*, mention'd before *, whoſe Legs *d* F, F *d*, would join the ſeparate Legs *d* I, *d* I. 3324. * 3314.

In the ſecond Scholium I ſhall ſpeak farther of theſe Curves, and ſhall demonſtrate what is only mention'd here; but now I ſhall briefly explain the Phænomena, which follow from what is ſaid.

Objects plac'd beyond the Center are ſeen between the Speculum and the Center; for all the Points appear in the Curve as F *l* *, *the Images of the Objects are* alſo *diminiſh'd and Inverted:* For they are reduced into a narrow Space; and in the Deſcent of the Point R the Repreſentation of it aſcends; for the Curve F *l*, keeps the ſame Poſition with Reſpect to R C *a*, which turns about the Center C. 3325. Plate 106. Fig. 5. * 3314. 3326.

Experiment 4.

That the Repreſentation of the Objects may not be leſs vivid by Means of the extraneous Light, the Speculum muſt be incloſs'd in the Box. Let there be a Speculum, the Diameter of whoſe Surface is about eight Inches, and which is a Portion of a Sphere of the Diameter of one Foot and a half; let this be incloſed in the Box P, in whoſe fore Part there is a Hole of the Diameter of about five Inches, and from which the Speculum is diſtant three or four Inches; it is neceſſary that this Aperture be turn'd from the Light. Now if any one at A, beholds himſelf at the Diſtance of about two Feet from the Speculum, his Face will appear inverted in the Box, towards the Aperture; if the Spectator approaches, his Head will appear to be out of the Box. 3327. Plate 106. Fig. 6.

The Repreſentation of a Point placed in the Center of the Sphere, coincides with the radiant Point itſelf, and is as it were ſwallowed up by it *. 3328. * 3318.

If the Eye be plac'd in that Center, no Object will be ſeen by it; for thoſe Rays only which come from the Eye are reflected to it *. 3329. * 3272.

If

3330. *If an Object be between the Center and the Point in which the parallel Rays that are reflected are collected, the Object* alſo *appears without the Mirror, at a greater Diſtance from the Mirror than the*
* 3319. *Object itſelf* * ; *and it's Repreſentation is inverted:* Which is proved in the ſame manner as in N. 3326; *and enlarged,* becauſe this is more diſtant from the Center than the Object is ; for the Repreſentation infinitely recedes from the Center, while the Object is
* 3320. moving through a fourth Part of the Diameter of the Sphere *.

3331. *If the Object be leſs diſtant from the Mirror than a fourth Part of*
Plate 107. *the Diameter of the Sphere, the Object will appear either before or*
Fig. 6. *behind the Mirror, according as the Eye is placed.* If the Eye be ſo placed, that the reflected Rays which form the Curve *l f l*, may come to it, it will ſee the Appearance of the Object magnified
* 3321. beyond the Mirror * ; becauſe the Curves, as *l f*, which belong to ſeveral Points, are diverging.

If the Rays, which form the Leg *d* I, come to the Eye, the
3332. Object will appear without the Mirror; and *in both Caſes the Repreſentation is erect*; for as the Point A riſes or falls, the Curves *l f*, *d* I, in which it is repreſented, are moved with the ſame Motion.

If the Eye be in the Point, in which reflected Rays, reaching to different Parts of the Curve, mutually interſect one another, *the*
3333. *Appearance of the Object may be double, or triple,* as at O ; but this cannot happen if the Mirror be made of too ſmall a Portion of a Sphere.

3334. It eaſily appears in every Caſe, that the Points of the Appearance have not the ſame Relation to one another, which the Points of the Object have ; and that therefore *a concave Speculum never repreſents an Object exactly :* But the Repreſentation is very irregular, which is in the Lines, as *d* I.

3335. With regard to which it is to be obſerv'd, which muſt alſo be referr'd to *l f*, *l f*, that the viſible Points are not in thoſe Curves unleſs near the Points *d*, *d*, and *f*, becauſe the Rays which belong to other Parts of theſe Curves and fill the Pupil, cannot be looked upon as Rays proceeding from one Point only.

3336. There are alſo cylindric, convex and concave Mirrors, as alſo conical convex ones ; in one reſpect they are plane, in another ſpherical: Therefore the Repreſentation of the Object is very irregular, which Irregularity, as it depends upon a regular Figure, may be determin'd in ſuch manner, that Figures may be drawn, which being really irregular, ſeem regular, in ſuch a Speculum, in a certain Poſition of the Eye.

SCHO-

SCHOLIUM I.

Of determining the Diameter of a burning Glaſs.

WHAT was explained in N. 3299, being given, the Angle DCE, to which BCA is equal, determines the apparent Magnitude of the Diameter of the Sun, and is equal to about 32′. The Diameter *b a* of the Image of the Sun is equal to half the Chord BA *, that is, it is equal to the Sine of the Arch 161, which, ſuppoſing the Radius AC = 100000, is equal to 465, and is to A*a* = 10000, as 1 to 108; whence appears what was ſaid in N. 3301. 3337. Pl.106.F.7. * 3297.

Rays parallel to the Ray CO, if they be at a ſmall Diſtance from it, being reflected paſs along *a*; if they be at a greater Diſtance they meet with CA between A and *a*, as follows from what is before demonſtrated *. But thoſe, which fall upon the Speculum between A and M, if they paſs along the ſmall Line *a b*, increaſe the Effect; but if the Arch AM is equal to twelve Degrees, the Ray GM being reflected along MH paſſes beyond *b* along *i*, and cannot aſſiſt the Combuſtion between *a* and *b*, as will appear from a Computation made. 3338. * 3297.

Let MN, the Sine of an Angle of twelve Degrees, be 20791; NC the Co-ſine of the ſame Angle 97815. 3339.

MHC is an Iſoſceles Triangle *, therefore HI, which is perpendicular to MC, divides this into two equal Parts at I; and HC is the half Secant of the Angle of twelve Degrees, when the Radius of the Circle is MC or CA; therefore HC = 51117; NC — HC = NH = 46698; HC — *a*C = H*a* = 1117. The Angle *i a* H wants ſixteen Minutes of a Right one; we take it for a Right one, becauſe no ſenſible Error ariſes from it; then the Triangles HMN, H*i a*, are ſimilar, and NH (46698) is to NM (20791), as H*a* (1117) is to *a i* (497): But *a b* as we have ſeen is only equal to 465. But when the Diſtance of the Sun from the Earth is leaſt of all, *a b* increaſes, and is equal to 480; ſo that very few of the Rays fall without the true Image of the Sun; for if AM ſhould want eight minutes of twelve Degrees, *a i* would be equal to 480. This is the Reaſon why we have determin'd the whole Arch MN, that is the Diameter of the Speculum, 25 Deg. *, leſt the Rays, which can increaſe the Effect, ſhould be wanting. * 3297. * 3303.

SCHOLIUM II.

Of cauſtic Lines by Reflexion.

THE curve Lines, mention'd in N. 3314, and the following, are call'd cauſtic Lines; we have explain'd how their Points may be diſcover'd *, and ſeen, that the Determination is not different from that deliver'd 3340. * 3315.

* 3277. † 3288. deliver'd for convex Speculums *, a Demonſtration of which we have given in the Scholium of the laſt Chapter †.

Pl.107.F.1. As there, ſo here alſo we have the following Proportion; which is demonſtrated in the ſame manner as there.

$$RD + 3RA, AB :: RA, FA.$$

but $RD + 3RA = 4RD + 3DA = 4RD + 4DE = 4RE$; for we ſuppoſe $AE = \frac{1}{4}AD$.

Therefore $4RE, 4AE :: RE, AE :: RA, FA$. Which was to be demonſtrated.

3341. The Demonſtration differs little from this when the Point R falls within the Circle.

Then $Aa - Dd = Bb - Aa$;

* 3289. Alſo inſtead of the Proportion $Dd + a, Aa :: RD + RA, RA$ *, we eaſily have this $Aa - Dd, Aa :: RA - RD, RA$.

* 3290. We alſo have $Bb - Aa, Aa :: FB - FA, FA$ *;

Therefore $RA - RD, RA :: FB - FA, FA$.

By Compoſ. and again by Comp. and Altern. $3RA - RD, AB = AD :: RA, FA$;

But $3RA - RD = 3RA + 3RD - 4RD = 3AD - 4RD = 4DE - 4RD = 4RE$.

* 3340. Therefore $4RE, 4AE :: RE, AE :: RA, AF$, as above *.

3342. From this Determination of the Point F we deduce, that the Point F is in the middle of the Chord AB, when the radiant Point is in the middle of the Chord AD; for then $RE = AE$; and therefore $RA = AF$.

3343. As the Radiant approaches the Focus recedes, and *vice verſa*.

3344. When the Radiant is at E, AE infinitely exceeds RE, which is equal to nothing; therefore AF infinitely exceeds RA, that is, the reflected

* 3320. Rays are parallel, as has been ſhewn *.

3345. If the incident Rays are parallel, of which we have ſpoken in N. 3307, we take the infinite ones, RA, RE as equal, therefore AF, AE are

* 3244. alſo equal; which alſo follows from the general Law of Refraction *,

3346. If the Radiant R be between E and A, the firſt Term of the Proportion RE is negative; therefore alſo the laſt AF, that is, the diverging Rays are reflected, as has been ſaid in N. 3321.

3347. In theſe four Figures we exhibit Curves, by conſidering the Reflexion

Plate 107. of the whole Circumference of the Circle. When the radiant Point R is

F.2,3, 4, 5. within the Sphere, there are four Points of the Inflection F, *f*, in the direct Ray, and two others *d*, *d*, in reflected Rays, ſuppoſing the incident Rays to be perpendicular to the direct Ray.

3348. But if the Radiant Point be without the Sphere, the Reflexion can only be in Part, without the Sphere at G*a*G, and in Part within at GAG, the firſt Part G*a*G being remov'd; in which Caſe there are only two Points of Inflection.

CHAP.

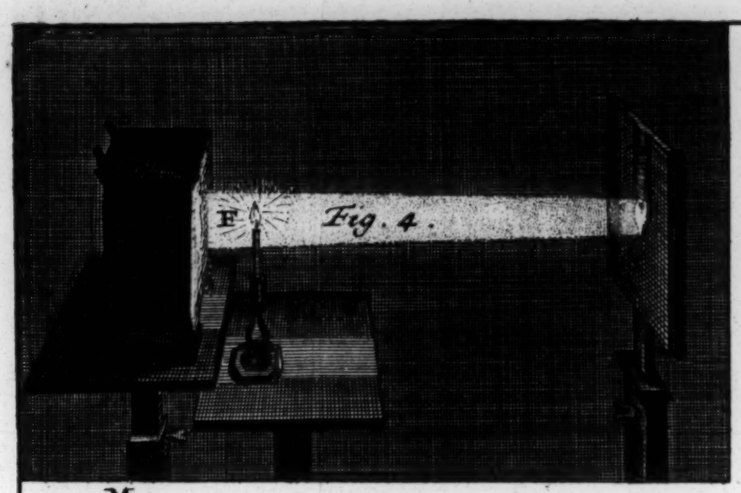
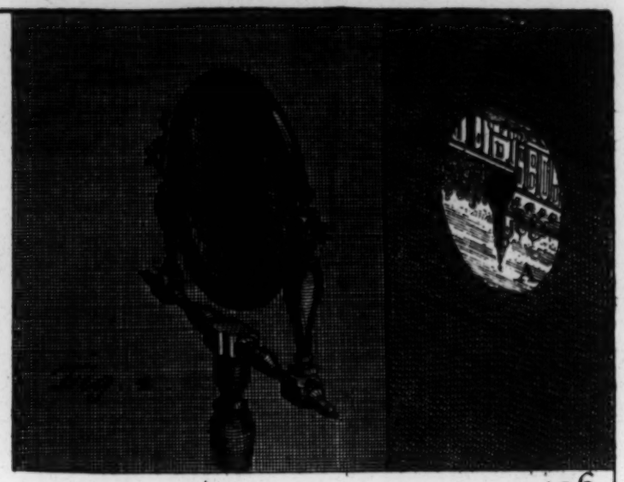


Fig. 4.



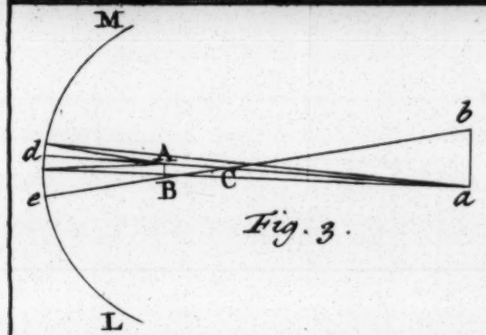


Fig. 3.

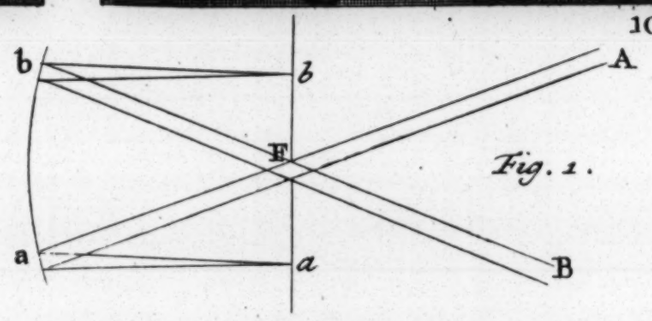


Fig. 1.

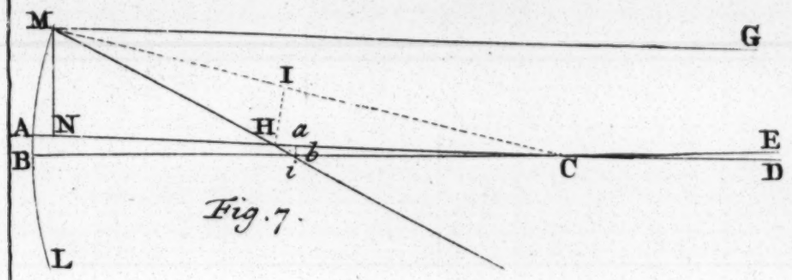


Fig. 7.

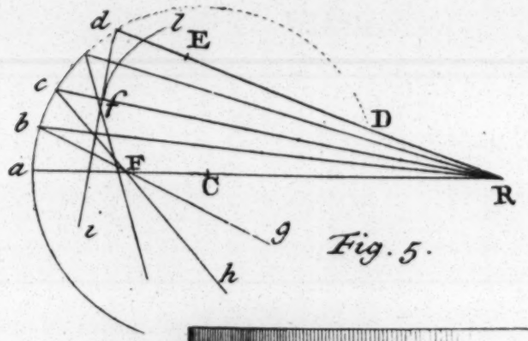
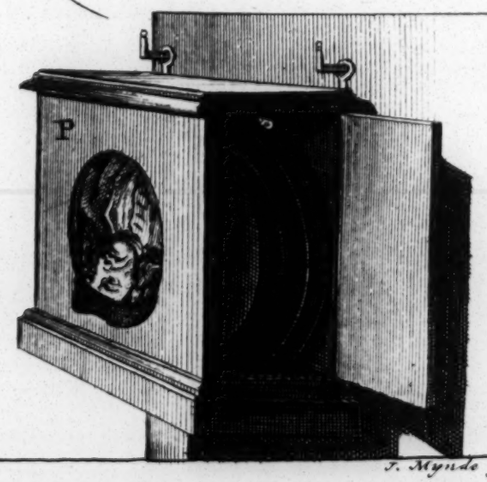


Fig. 5.



Fig. 6.



T. Mynde sc.

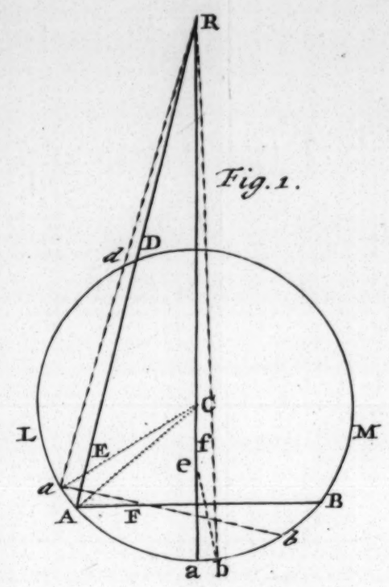


Fig. 1.

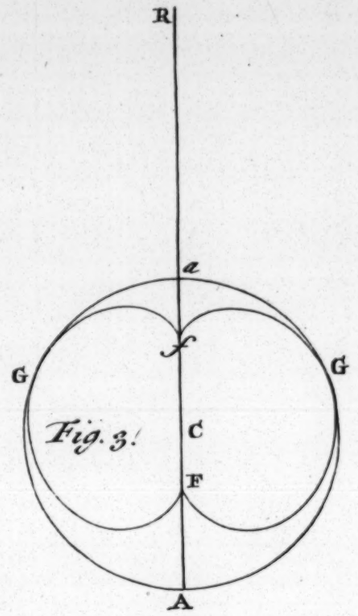


Fig. 3.

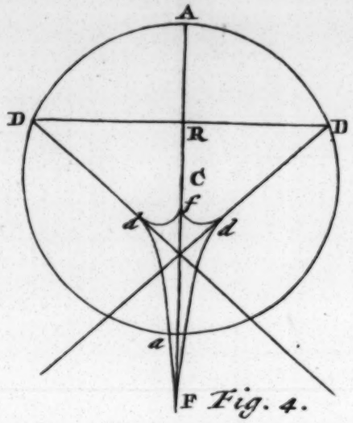


Fig. 4.

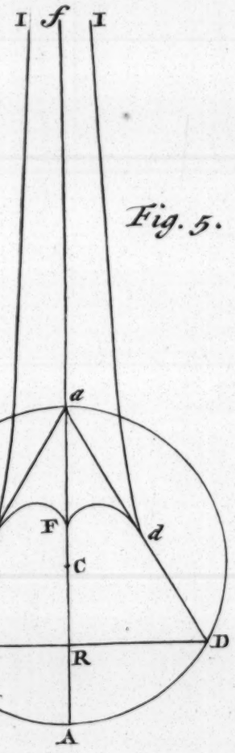


Fig. 5.

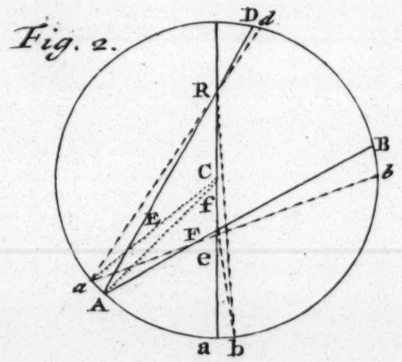


Fig. 2.

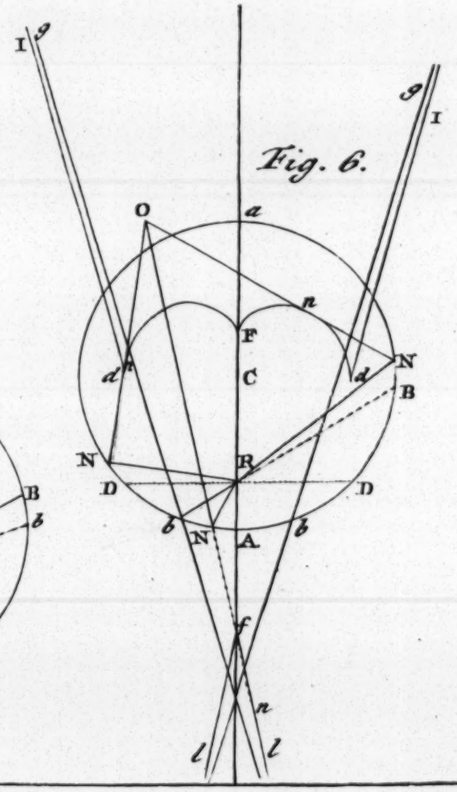


Fig. 6.

CHAP. XVII.

Of catoptric Teleſcopes.

WE have ſeen that Teleſcopes, made of Glaſſes, are imperfect for two Reaſons *; and we have only conſider'd that Defect, which follows from the Nature of Refraction. 3349. * 3221.

When we uſe Speculums inſtead of Glaſſes, the Imperfection from the Figure only takes Place (for we don't ſpeak here of the Matter, or Induſtry of the Workman); and as this Defect is very ſmall, the Teleſcopes, of which I now ſpeak, are more perfect than others.

Let there be a concave Speculum A A; C the Center of the Sphere, Q the Center of the Speculum itſelf, C Q a Ray proceeding from a Point of a diſtant Object, being reflected returns into itſelf, and with this, the Rays, proceeding from the ſame Point, which are looked upon as parallel, being reflected, meet at F, the middle Point between C and Q *. 3350. Plate 108. Fig. 1. * 3297.

In the ſame manner, if C *q* be a Ray proceeding from any other Point at a Diſtance, and paſſing through the Center C, this being reflected, meets together with the neighbouring parallel and reflected Rays at E, the middle Point of the Line C *q*; and thus of any other diſtant Points whatſoever, from which Rays can come to the Mirror. Thus the Image of a diſtant Object is made, and it is made by direct Rays, wherefore this is perfect, if the Mirror, or rather the Aperture of the Mirror, be not too large *. This Image differs from that, which has been ſpoken of above †, which is made by oblique Rays; and yet it is accurate enough, becauſe the Rays which are but a little diſpers'd are collected; but in the Teleſcope ſuch an Image would be of no Uſe. * 3298. † 3309.

A ſmall plane Mirror B B is plac'd upon the Axis C Q in ſuch manner as to make an half Right Angle with it. This Mirror, though ſmall, intercepts many Rays; but by that the Image is only weaken'd a little, for only the ſmaller Part of the Rays, which proceed from any Point of the Object, and tend to all the Points of the greater Speculum, is intercepted, the other being reflected meet and make an Image of the Point; or rather would make it, if they were not all intercepted, being reflected from the ſmaller Mirror. 3351.

3352. Whilſt they are thus intercepted, they are reflected from the ſmaller Mirror in ſuch manner, as to be before the Mirror, as they would be behind the Mirror, if they were to continue their Motion through it; which follows from the Demonſtration deliver'd in N. 3264; therefore the Image is transfer'd to *f e*. Now if we
* 3195. obſerve this through the Eye Glaſs O O *, we ſhall have the Object very much enlarged. The Place of the Eye is determin'd,
† 3189. 3197. as has been ſeen above †.

3453. The Aperture of ſuch a Teleſcope is very large, if it be com-
* 3221. pared with the Aperture of a dioptric Teleſcope *, therefore the Picture in the Eye may be very much enlarged by making uſe of an
† 3220. acute Eye Glaſs, ſufficient Clearneſs being preſerved †. In which Caſe alſo the Viſion is diſtinct, becauſe the Aperture is indeed enlaarg'd, but yet ſo that the Image remains diſtinct.

3354. *The apparent Magnitude in this Teleſcope is* refer'd *to the apparent*
* 3207. *Magnitude to the naked Eye, as* has been ſaid of other Teleſcopes *; and that is to this, as the Angle O D *d* is to the Angle F C E, but as theſe Angles have the equal Baſes *d* O and F E (for ſuch are F E, *f e*, and this to Senſe does not differ from *d* O) and as theſe
† 3158. are ſmall †, for they are to one another as S C, or Q F to D *d*; that is, as the Diſtance, at which the Mirror collects parallel Rays,
‡ 3215. which is *the Length of the Teleſcope* ‡, *is to the Diſtance, at which the Eye Glaſs collects parallel Rays.*

3355. What has been ſaid of the Perfection of Teleſcopes made of
* 3213. Glaſſes *, muſt be refer'd to theſe alſo; we muſt diſcover by Experience what is beſt for any given Speculum; that is, we ought to ſeek the Magnitude of the Aperture by Trial, by applying dif-
† 3227. ferent Eye Glaſſes, ſeveral times †, that thus, when the Length of the Teleſcope is given we may determine the Aperture, and the Diſtance of the Focus of parallel Rays for the Eye Glaſs.

3356. Let it be now thus diſcover'd, that an Aperture of five Inches anſwers to a Length of five Feet, and that an Eye Glaſs is to be made uſe of which collects parallel Rays at the Diſtance of the third of an Inch; when a Teleſcope of a different Length ſhall be to be conſtructed equally perfect, that is, which may repreſent Objects, equally diſtinct, and with the ſame Clearneſs, we ought to obſerve this Rule, which we ſhall demonſtrate in the ſecond following
3357. Scholium, that *the Length of Teleſcopes be to one another as the fourth Powers of the Diſtances of the Foculſes of the Eye Glaſſes, and that the Diameters of the Apertures be as the Cube of the ſaid Diſtances*;
* 3358. then alſo *the Amplifications of the Lines are as the Diameters of the Apertures.*

But

But the Aperture muſt be altered according to the different Light of Objects *; and it is proper alſo to make uſe of different Eye Glaſſes according to different Circumſtances. 3359. * 3230.

Objects appear inverted in this Teleſcope; but they are made to be erect by adding two Eye Glaſſes *. 3360. * 3199.

This is called the *Newtonian* Teleſcope, from the Inventor of it; it was propoſed near ſeventy Years ago, but it was happily brought to Practice in *England* by Mr. *John Hadley*, and carried to Perfection about twenty Years ago. 3361.

Mr. *James Gregory* had before invented another catoptric Teleſcope, ſuch as are now commonly uſed: and theſe were brought to Perfection a little after the *Newtonian* ones. 3362.

The *Newtonian* Teleſcope is more ſimple and more perfect, and much to be prefer'd to the other for celeſtial Obſervations; the *Gregorian* Teleſcope is moſt convenient for ſeeing terreſtrial Objects. 3363.

This conſiſts of a great concave Mirror, ſuch as is uſed in the *Newtonian* Teleſcope; of a leſs concave Speculum and of one, or as they are now conſtructed, two Eye Glaſſes. This is the Diſpoſition of the Parts. 3364.

A A is the larger Speculum; this is perforated in the middle, and Q the Center of the Mirror is alſo the Center of the Hole *m* Q *n*; the Axis of the Teleſcope, which paſſes through the Center of the Sphere, and the Center of the Mirror, is C I. The ſmaller Mirror B B, upon which the Rays fall that are reflected from the greater Mirror, is ſo placed, that it's Axis *s c*, which paſſes through *c* the Center of the Sphere, and *s* the Center of the Mirror, may coincide with the Axis of the Teleſcope C I. The firſt Eye Glaſs V V is plac'd behind the Hole in the larger Mirror; the ſecond is plac'd at O O, and they have their Axes in the ſaid Axis C I. 3365. Plate 108. Fig. 2.

Let C Q and C *m* be Rays proceeding from two Points of a diſtant Object, and mutually interſecting one another in the Center C in theſe Lines, although the Rays be intercepted, the Images of the Point are at E and F, as has been explained in the *Newtonian* Teleſcope *, and E F repreſents the Image of the diſtant Object. 3366. * 3351.

This Image may be conſidered as an Object which, ſetting aſide the Lenſe V V, would have it's Image *f e* by the Reflexion of the Mirror B B *; which ſecond Image may be remov'd to any Diſtance from E F; for this depends upon the Poſition of the ſmall Mirror, which is to be ſo plac'd that E F may be between *c* and *p*, but this is the middle Point between *c* and *s* *, but by diminiſhing *p* F *f e* is remov'd. 3367. * 3311. * 3310.

This

3368. Every Point of the Image E F would be made by Rays proceeding from all the Points of the Mirror A A, if none of the Incident Rays were intercepted by B B, or paſſed through the Hole A A; then among the Rays, that make a Point as E, there would be one as *n c* E *i*, which would paſs through the Center *c* of the Sphere of the ſmaller Mirror; and this being reflected, would return into itſelf, and tend to the Point *e* of the ſecond Image; for all the Rays proceeding from E, and reflected from the ſmaller Mirror, paſs along *e*, and drawing Lines from all the Points of the Image *e f*, through the Center *c*, theſe will paſs through the correſpondent Points of the Image *e f*.

3369. Now let us ſuppoſe the Eye Glaſs V V to be placed near the Hole of the greater Mirror in ſuch manner that it may intercept all the Rays paſſing through it. The ſaid Rays, that paſs through *c*, fall upon the Glaſs diverging, and go out converging, tending
* 3011. towards I *. But the Rays that tend towards the Point as *e* con-
† 3012. verge more †, and meet at the Point *e*, which is at a leſs Diſtance; and thus a third Image *e f* is made, through all the Points of which the Rays tend to I.

3370. This laſt Image appears magnified through the Lenſe O O, and this is the Uſe of this Teleſcope. But the Rays that tend towards
* 3012. I, and are converging, converge more, and meet at D *; and this is the Place of the Eye; for unleſs this be placed there, all the Rays, paſſing through the Eye Glaſs O O, will not be able to penetrate into the Eye, and the Field would be leſs, as has been
* 3189.3197. often ſeen *.

3371. The Plate is faſten'd at D, in whoſe Center there is a ſmall Hole. This excludes all extraneous and troubleſome Light; which, when the Hole Increaſes a little, enters into the Eye.

3372. When one Eye Glaſs only is made uſe of, the Image, *e*, *f*, is
* 3362. plac'd at a ſmall Diſtance from the Hole *n m* *, and a Spectator beholds this through the Eye Glaſs.

3373. The Amplification, that is the Increaſe of the apparent Magnitude, is determined in this Teleſcope as in the others; for this Magnitude to the naked Eye, is to that ſeen through the Teleſcope as
* 3207.3352. the Angle E C F to the Angle *x* D *d* *, the Compariſon of which is more intricate than in the Examples which we have hitherto had.

3374. But the apparent Magnitude through the Teleſcope is to that with the naked Eye, in this Caſe, as we demonſtrate in the third Scholium following, in a Ratio compounded of theſe three Ratios of

of F Q to F *c* of *c y* to *y r* (*y* is the Focus of parallel Rays of the Glaſs V V) and laſtly of *f* I to *f d*; we ſuppoſe *f* to be in the Focus of the Glaſs O O, from which this Image is hardly removed, except there be a fault in the Eye of the Spectator. The Antecedents and Conſequents being multiplied, there is produced the Ratio which we ſeek.

We diſcover by Trial what is required to make the Teleſcope as perfect as poſſible, as has been ſeen of other Teleſcopes *; and we afterwards determine by Computation, how another equally perfect, that is, which repreſents Objects equally clear, and equally diſtinct, may be conſtructed; but the Trials made with the *Newtonian* Teleſcope * are of uſe here alſo. 3375. * 3227. 3355. * 3356.

But as the Teleſcope, ſpoken of here, conſiſts of many Parts, this may be alter'd many Ways, keeping the abovementioned Perfection. 3376.

We now ſuppoſe, a Teleſcope being given, whether a *Newtonian*, or *Gregorian* one, with one or two Eye Glaſſes, that another equally perfect is to be made, whether *Newtonian*, a Speculum being given, or *Gregorian*, two Speculums being given, and the Lenſe V V, if two are to be made uſe of; theſe Parts being join'd at Pleaſure, yet in ſuch manner that the Image *e f*, if V V be wanting, or *e f* if V V be preſent, be plac'd in ſuch manner, that the Lenſe O O may be conveniently fitted to the Teleſcope. The Aperture of the greater Speculum is ſought, and the Convexity of the Glaſs O O. 3377.

We don't want a new Rule to determine the Aperture from that, which we gave for the *Newtonian* Teleſcope *, it follows, that *the Diameters of the Apertures in different Teleſcopes, are to one another as are the Cubes of the biquadratic Roots of the Lenghts.* The ſame Rule obtains in theſe, if we take the Diſtance F Q for the Length, as in the *Newtonian* Teleſcope. But before we determine the Convexity of the laſt Eye Glaſs, we muſt determine the Ratio, which is between the Image which we ſhould obſerve through this laſt Lenſe O O, and the firſt Image E F. If the Lenſe V V be wanting, this Ratio is (as will be ſeen in the third Scholium) that which is given between *p s* and F *p*. * 3357. 3378. 3379.

If two Glaſſes are to be made uſe of, and V V be given, we have *f*; for *p* F, *p c*, *p f*, are proportional, as follows from the Proportion abovemention'd *, we diſcover I, becauſe *c y*, *c r*, *c* I, are alſo in continued Proportion †. We alſo diſcover *f*, for *f y*, *f r*, *f f*, are alſo Proportionals ‡. Theſe being given, the Ratio ſought, which 3380. * 3310. † 3035. ‡ 3035.

is between *ef* and E F, is as we ſhall ſee in the third Scholium, made up of the Ratios now known, of I*f* to *yr* and *cr* to *c*F, the Antecedents and Conſequents of which ſhould be multiplied.

3381. But the Ratio between the Diameters of the laſt Image and the firſt being given, by dividing the Antecedent by the Conſequent, we have the Exponent of the Ratio of the firſt Amplification, for ſo we ſhall call it, to diſtinguiſh it from the Amplification, which the Teleſcope itſelf produces.

This Exponent being multiplied by the Square Root of the Length of the Teleſcope, the Product is in the Ratio of the Diſtance *df*, that is of that, at which the Glaſs O O collects parallel Rays,

3382. which alſo we expreſs in this manner. That *in different Teleſcopes, the laſt Eye Glaſſes muſt be ſo conſtructed, that the Products of the Exponents of the firſt Amplifications by the biquadratic Roots of the Lengths, may be to one another as the Diſtances of the Focuſſes of the ſaid Lenſes*; which Rule is demonſtrated in the fourth Scholium.

3383. With regard to theſe Computations the *Newtonian* Teleſcope differs from the *Gregorian* in this only; in the firſt a Spectator ſees the Image equal to E F through the Eye Glaſs, in the ſecond he obſerves the Image *ef*.

3384. If the Images *ef* and E F in the *Gregorian* Teleſcope be equal, ſetting aſide the Diminution of Light from the Reflexion and Refraction, theſe Images will alſo be equally lucid; ſo that it matters

3385. not which we behold; and *the* Newtonian *Teleſcope is compared with the* Gregorian, *if inſtead of the* Newtonian *we conceive a* Gregorian *Teleſcope* in which the ſaid Images are equal, that is, *in which the Exponent of the firſt Amplification is Unity.*

3386. Therefore it is not neceſſary, as has been ſhewn above *, when

* 3375. the Aperture and Convexity of the Eye Glaſs for the *Newtonian*

† 3356. Teleſcope are determin'd by Experiments †, to make new Trials, in order to conſtruct a *Gregorian* Teleſcope equally perfect: The Computation may be made with thoſe Things given which were mention'd in N. 3377.

3387. When two Teleſcopes, the one *Newtonian*, the other *Gregorian*, are of equal Lengths, that is, when the greater Speculums are equally concave, unleſs the Apertures of the Speculums be equal, they

* 3383.3384. will not be equally perfect *; and if they be equally perfect, Objects will appear equally magnified, howſoever the Figure and Poſition of the ſmaller Speculum, and inner Glaſs be varied in the *Gre-*

3388. *gorian* one, for *the Rule*, mention'd above, in a peculiar Caſe *, *is*

* 3358. *univerſal, which takes Place in the Com pariſon of any Teleſcopes whatever*,

ever whether of the ſame or of a different Kind, that the Amplifications of Objects are as the Apertures when the Clearneſs is the ſame.

For the Clearneſs depends upon the Light, with which the Picture of an Object in the Eye is illuminated; if the Light be alter'd, the Clearneſs will remain the ſame in this Caſe only, if the Picture be alter'd in the ſame manner; for Example, if it be doubled, when the Light is doubled, *&c.* that is, the Picture and Light ought to be in the ſame Ratio; but the Light is as the Aperture *, therefore the Picture is in the ſame Ratio alſo. 3389. * 3220.

In the laſt Scholium of this Chapter, I ſhall demonſtrate the Rules concerning the Compariſon of the *Gregorian* Teleſcopes; and I ſhall alſo ſpeak of comparing dioptric Teleſcopes with catoptric ones; concerning which Compariſon I ſhall only give one Rule here, which will have for it's Foundation this, *viz.* that the Teleſcopes mention'd in N. 3228, and 3356, are equally perfect.

The Length of any dioptric Teleſcope equally perfect with that mention'd in N. 3228, being given, we want to know the Length of a catoptric Teleſcope, which, if it be as perfect as the other, repreſents Objects amplified equally with the Teleſcope propoſed. The Rule is this. 3390.

The Square of the given Length is divided by $55\frac{5}{9}$, *and the Cube Root of the Quotient expreſſes the Length ſought.* 3391.

If the Length of the catoptric Teleſcope were given, and that of the dioptric one ſought, the Cube of the given Length ſhould be multiplied by $55\frac{5}{9}$, and the Square Root of the Product would give the Length. 3392.

But this Number $55\frac{5}{9}$ was determin'd for Lengths, expreſſed in *Rhinland* Feet, therefore a Length of ſix Inches ſhould be expreſſed no otherwiſe than by $\frac{1}{2}$, or O, 5. 3393.

SCHOLIUM I.

Of the ſpreading of Rays from the Reflexion of a concave Speculum.

LET there be a concave Speculum ML; C the Center of the Sphere; DCA a direct Ray; *a* the Focus of Rays parallel to it, dividing CA into two equal Parts *; let there be other parallel Rays alſo at a greater Diſtance, and the laſt of theſe BM, which is reflected along MH*i*. When the Rays are at a ſmall Diſtance, from A, being reflected they meet at *a*; but this laſt cuts CA in H; and if the parallel Rays take up a Space on the Surface of the Mirror, whoſe Semi-Diameter is AM, that is, if this be the Semi-Diameter of the Aperture; all theſe being reflected 3394. Pl. 108. Fig. 3. * 3297.

flected paſs through the ſmall Space whoſe Semi-Diameter is *a i*; many Rays indeed mutually interſect one another every where between H and *a*; but they are collected no where in ſo great Plenty as at *a:* And therefore the Diſperſion is to be referr'd to this Point at *a*, and there meaſur'd.

3395. This ſmall Line *a i*, if H*a* remains, is as the Angle *a* H *i* or MHA; if the Angle be not alter'd, the ſame ſmall Line *a i*, is as H*a*; therefore, as theſe two are continually chang'd, when M recedes or approaches, *a i* is in a Ratio compounded of the two.

3396. MHC is an Iſoſceles Triangle *; therefore the Angle MHA is
* 3297. double the Angle MCA†; and therefore MHA is in the Ratio of
† 32. El. 1. the Arch AM.

3397. With the Center C, through the Point *a* decribe a Circle, which cuts the Line CM in I; in which Point if there be a Perpendicular to CM,
* 16. El. 3. it will touch the Circle at I*; and paſs through H, by reaſon that HC, HM are equal. Let D be the End of the Diameter of the ſame Circle, and the Square of the Line HI will be equal to the Rectangle made of
* 36. El. 3. HD multiplied into H*a**. But as we only ſpeak of the Caſes in which H*a* is ſmall, HD is taken as conſtant; and the ſaid Rectangle is in
* 1. El. 6. the Proportion of H*a**; in the Ratio of which therefore is the Square of the Line HI. But HI to Senſe agrees with the Arch *a* I, which is in the Ratio of AM; therefore H*a* is in the duplicate Ratio of the Arch AM; if with theſe be join'd the Ratio of the ſame Arch, which
* 3396. is the Ratio of the Angle AHM*, we have the triplicate Ratio of
† 3395. AM, in which Ratio is *a i* †.

3398. Therefore *the Diameter of the Diſperſion, is as the Cube of the Diameter of the Aperture, in the ſame Mirror.*

3399. Let us now ſuppoſe, the Mirrors to be different, but the Apertures equal. Let *m n* be a Mirror; *c* the Center of the Sphere; *c a* a direct Ray; *f* the Focus of parallel Rays; *a m* the Semi-Diameter of the Aperture, equal to A M. The laſt Ray *b m* is reflected along *m r p*, and the Semi-Diameter of the Aberration is *p f*, which we muſt compare with *a i*.

Let us ſuppoſe *a n* to be to *a m*, as *a f* is to A*a*; and let the incident Ray at *n* be reflected along *n h o*; ſo that *f o* may be the Semi-Diameter of the Diſperſion, when *a n* is the Semi-Diameter of the Aperture.

From the Conſtruction it follows that the Figures A H *a i* H M and *a h f o h n* are ſimilar;

And therefore *a i*, *f o* : : A*a*, *af*.

* 3398. We alſo have *f o*, *f p* : : an^3, am^3 * : : af^3, Aa^3.

But *a i* is to *f p* in a Ratio compounded of the Ratios of *a i* to *f o* and *f o* to *f p*; that is of the Ratio's of A*a* to *af* and af^3 to Aa^3, or $\frac{I}{Aa^2}$ to $\frac{I}{af^2}$.

3400. Therefore, *when the Aperture is determin'd, the* Semi-*Diameter of the Diſperſion*, which is as the whole Diameter, *is in the inverſe duplicate Ratio of the Diſtance of the Focus of parallel Rays*, or the Length of the Teleſcope, if this be conſider'd.

We

We have now a general Rule concerning the Diſperſion; that *the Diameter of the Spot, which the diſperſed Rays make, is in the direct triplicate Ratio of the Aperture of the Mirror* *, *and the inverſe duplicate Ratio of the Diſtance of the Focus of parallel Rays* †. 3401. * 3398. † 3400.

SCHOLIUM II.

Of comparing together the Newtonian *Teleſcopes.*

CAtoptric Teleſcopes are compar'd together, as has been ſaid of dioptric ones; thoſe are equally perfect, which repreſent Objects equally diſtinct, and equally clear *. The Clearneſs in theſe, as in the others, is directly as the Aperture, and inverſly as the Picture of the Object in the Eye †. But the Diameter of this Picture is in the direct Ratio of the Diameter of the Image in the Teleſcope, which is as it's Length, and the inverſe Ratio of the Diſtance of the Focus of the Eye Glaſs; for all theſe Things agree to this Teleſcope in the ſame Manner as to thoſe, which are made of Glaſſes *. 3402. * 3225. † 3231. * 3231.

Let a be the Diameter of the Aperture; l the Length of the Teleſcope; f the Diſtance of the Focus of the Eye Glaſs; the Clearneſs of the Teleſcope will be as the Square of this Fraction $\frac{af}{l}$ *. 3403. * 3231.

This Fraction is not alter'd, by altering the Length of the Teleſcope at Pleaſure, if the Rule of N. 3357 be obſerv'd. According to which a is as f^3, af as f^4; l alſo is as f^4; therefore the Numerator and Denominator of the Fraction are alter'd in the ſame Ratio; and this, which is in the ſubduplicate ratio of the Clearneſs, is not alter'd. 3404.

The Diſtinction is the ſame, when the Spot in the Bottom of the Eye, which repreſents a Point, has the ſame Magnitude *; but this Spot in the Eye is the Picture of another Spot, which the Rays, that proceed from a Point of the Object, make in the Image of it. 3405. * 3232.

The Diameter of this laſt Spot is as $\frac{a^3}{l^2}$ *. But the Picture of this Diameter, is as AD directly, and inverſly as the Diſtance of the Focus of the Eye Glaſs †. Therefore the Diameter of the Spot in the Eye is as $\frac{a^3}{l^2 f}$. Now if, according to the Rule ‖, a be as f^3, and l as f^4, the Numerator and Denominator of the Fraction are both in the Ratio of f^9; that is, they are increaſed, and diminiſh'd in the ſame Ratio, and the Fraction is not alter'd, and the whole Picture in the Eye is equally diſtinct. * 3401. † 3231. ‖ 3351.

SCHOLIUM III.

Of determining the Amplifications in the Gregorian *Teleſcopes.*

3406. WE ſaid that the apparent Magnitude to the naked Eye is to that
Plate 108. through the *Gregorian* Teleſcope, as the Angle E C F, is to the
Fig. 2. x D d *; but this Ratio is compounded of the Ratios of the Angle E C F
* 3373. to E c F or $t\,c\,r$; or $t\,c\,r$ to t I r; and laſtly of t I r, which is x I d, to x D d. The firſt Ratio is that which is between F c and F C, or F Q;
* 3035. the ſecond is between I r and $c\,r$, but $c\,y$, $c\,r$, c I, are proportional *; and by Inverſ. and Diviſ. $c\,r - c\,y = y\,r$, $c\,y$: : c I $- c\,r =$ I r, $c\,r$; therefore the ſecond of the ſaid three Ratios is that, which is between $y\,r$ and $c\,y$; the third is that between D d and I d; but I f, I d, I D are
* 3035. Proportionals *; by Converſ. and Inverſ. I f — I $d = f\,d$, f I : : I d — I D = D d, I d, and the third Ratio is that between $f\,d$ and f I; but theſe Ratios are the ſame, as thoſe mention'd in N. 3374.

What has been ſaid in N. 3379 and 3380 about determining the firſt Amplification, that is, about comparing the different Images of Objects, ſhall be now examin'd alſo.

3407. Let us ſuppoſe one Eye Glaſs only, to be made uſe of, and we muſt demonſtrate that, which is deliver'd in N. 3379, namely, that $p\,s$ is to F p as $e\,f$ is to E F, that is, as $f\,c$ is to c F.

3408. We have $f\,s$, s F : : $p\,s = p\,c$, F p *.

* 3310. By Diviſion $f\,s - s$F $= f$F, s F : : $p\,c -$ F $p = c$ F, F p.
By Altern. and Diviſ. fF $- c$ F $= f\,c$, c F : : sF $-$ F $p = p\,s$, F p. Q.D.E.

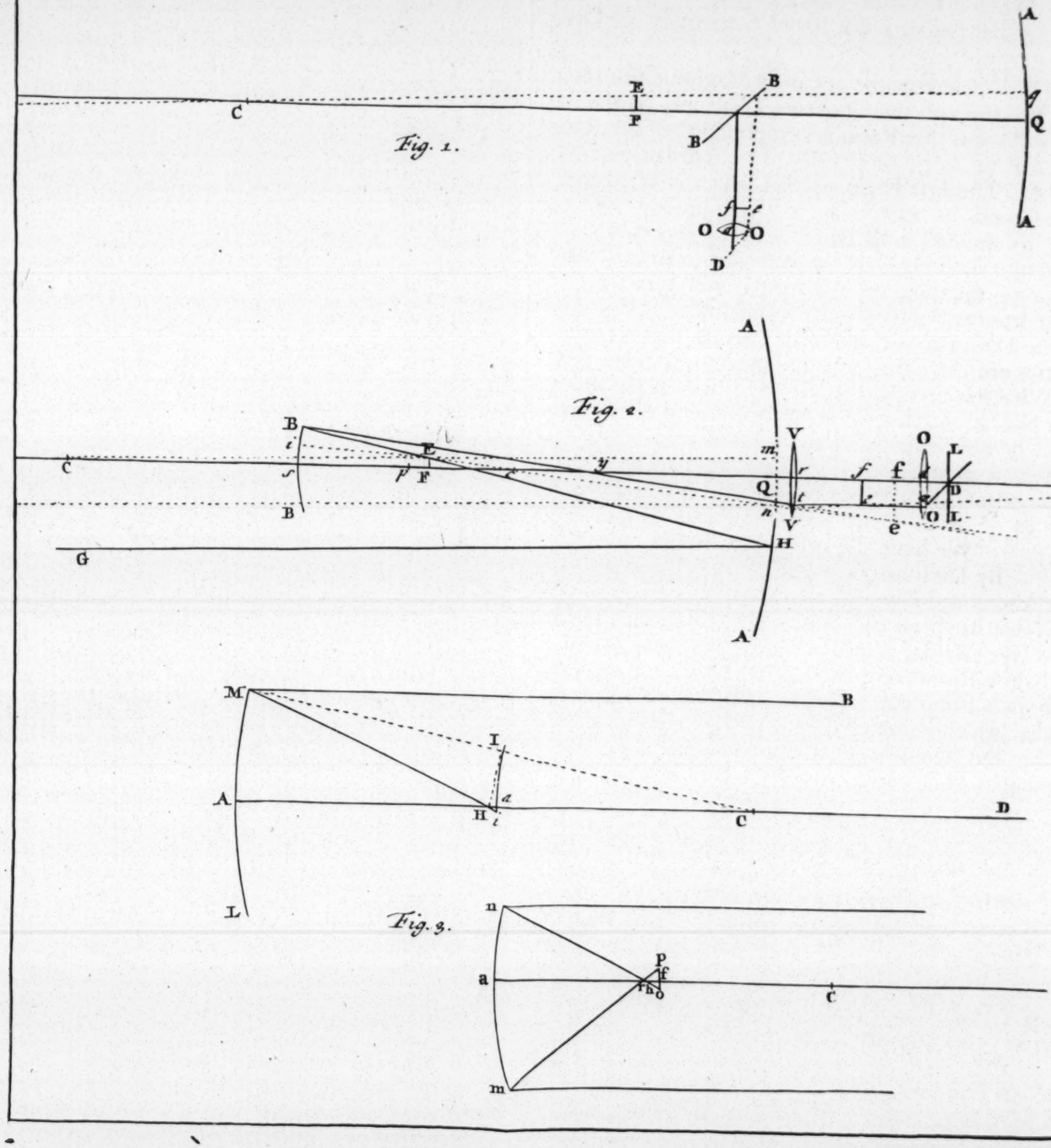
3409. What has been ſaid in N. 3380, concerning the firſt Amplification with two Eye Glaſſes, ſcarce needs to be demonſtrated; namely that $e\,f$ is to E F in a Ratio compounded of I f to I r and $c\,r$ to c F; for $e\,f$ is to E F in a Ratio compounded of $e\,f$ to $r\,t$ and $r\,t$ to E F; but the firſt is that which is between I f and I r, by reaſon of the ſimilar Triangles $r\,t$ I, $f\,e$ I. But the ſecond Ratio of $r\,t$ to E F, by reaſon of the ſimilar Triangles $c\,t\,r$, c F E, is that, which is between $c\,r$ and c F.

SCHOLIUM IV.

Of comparing the Gregorian *Teleſcopes with one another, and with the* Newtonian *Teleſcopes; as alſo of comparing catoptric and dioptric Teleſcopes.*

3410. WHAT was delivered in the ſecond Scholium, is of Uſe here alſo; therefore we again ſuppoſe a to expreſs the Diameter of the Aperture of the Teleſcope; l the Length; and f the Diſtance of the Focus of the laſt Eye Glaſs, that is, of that next the Eye.

Let


A
B
E
C
F
Q
B
A
f
e
O
O
D
Fig. 1.
A
Fig. 2.
B
V
O
L
m
E
C
f
f
I
i
p
F
y
Q
r
t
n
V
B
G
H
A
M
B
I
A
a
H
i
C
D
L
Fig. 3.
n
p
f
a
h
C
m

Let us moreover ſuppoſe, any Line in the laſt Image, which a Spectator beholds immediately, through the Glaſs next to the Eye, to be to the ſame Line in the firſt, which is made by the greater Speculum, as n to 1; ſo that n may be the Exponent of the firſt Amplification *. The Teleſcope being now given, another, of any Length, is propoſed to be conſtructed in ſuch manner, that Objects may appear equally diſtinct and clear. * 3381.

As the Length of the Teleſcope is given, the greater Speculum is given, whoſe Aperture is to be determin'd; the Convexity of the laſt Eye Glaſs muſt be determin'd, and theſe two things are ſufficient; for there are only two Conditions of the Problem, that the Clearneſs and Diſtinctneſs may be preſerv'd; wherefore the ſmaller Speculum may be varied at Pleaſure, and the firſt Eye Glaſs, when two are uſed; theſe two may alſo be plac'd at Pleaſure, but Care muſt be taken that the Caſe be not impoſſible or inconvenient *. 3411. * 3377.

The Clearneſs of the Teleſcope is directly as the Aperture, and inverſly as the Picture in the Eye; the Diameter of the Picture is directly as the Image, and inverſly as f*, the Diameter of the firſt Image is as l †, but we ſpeak of the ſecond, whoſe Diameter is as nl ‖; therefore the Diameter of the Picture is as $\frac{nl}{f}$, and the Clearneſs in the duplicate Ratio of this Fraction $\frac{af}{nl}$ ‡. 3412. * 3231. † 3214. ‖ 3410. ‡ 3403.

The Diſtinctneſs of every one of the Points is had by conſidering the Spot, which repreſents a Point of the Object in the Image, the Diameter of which Spot is as $\frac{a^3}{l^2}$ *, this in the laſt Image is as $\frac{na^3}{l^2}$, and the Picture of it in the Eye as $\frac{na^3}{fl^2}$ †. 3413. * 3401. † 3403.

If therefore the Clearneſs and Diſtinctneſs of Teleſcopes be the ſame, theſe Fractions $\frac{af}{nl}$ and $\frac{na^3}{fl^2}$ are alſo conſtant for all Teleſcopes equally perfect. Therefore we may put each Fraction equal to a conſtant Quantity, which we denote by Unity; but theſe are not therefore equal to one another; becauſe we do not ſpeak of the ſame Unity for both Fractions.

We have now two Equations, which we change into theſe $af = nl$ and $na^3 = fl^2$; either gives the Value of f; which being compar'd we have $\frac{nl}{a} = \frac{na^3}{l^2}$, that is, $l^{\frac{3}{4}} = a$, as has been ſaid in N. 3378, where we obſerv'd, that this Rule agreed with that which was given for the *Newtonian* Teleſcope; wherefore *in all catoptric Teleſcopes, the Aperture is determin'd in the ſame Manner, which depends upon the Length alone.* 3414. 3415.

Whence

3416. Whence we deduce, that *the Amplification of an Object ſeen through a Teleſcope, depends* alſo *upon the Length alone*; for this remaining the ſame
* 3388. the Aperture remains, which is in the Ratio of the Amplification *.

3417. Therefore in all Teleſcopes, of the ſame Length, equally perfect, Objects appear of the ſame Magnitude, whether they be *Newtonian*, or *Gregorian* Teleſcopes, or if inſtead of a ſmall concave Speculum, they have a convex one; ſuch as *Caſſegrain* propoſed; who, although he propoſed his Teleſcope, which differ'd little from the *Gregorian* Teleſcope, a long Time after the Deſcription of the *Gregorian* Teleſcope was made publick, call'd himſelf the Inventor, becauſe, as it ſeems, he had not ſeen *Gregory*'s Book.

3418. Now to diſcover f, we muſt have Recourſe to the Equation $af = nl$ *;
* 3414. inſtead of a I ſubſtitute the Value $l^{\frac{3}{4}}$ and there is given $fl^{\frac{3}{4}} = nl$, or $f = nl^{\frac{1}{4}}$,
† 3382. as has been ſhewn above †.

3419. We have ſeen that n in the *Gregorian Teleſcope* may be changed at
* 3377. Pleaſure *; then all Things remaining the ſame f only muſt be changed in the ſame Ratio; for l remaining, f is changed as n, in the laſt Equa-
† 3385. tion in the *Newtonian* Teleſcope $n = 1$ †; and, if this be compar'd with the equal *Gregorian* Teleſcope, the Diſtances of the Foci of the Eye Glaſſes will be to one another, as 1 to n; and thus any catoptric Teleſcopes are compar'd together.

3420. But if dioptric Teleſcopes are to be compar'd with catoptric ones, two Determinations by Experiments are requir'd. For the Diſperſion of the Rays, upon which the Diſtinctneſs of the Objects depends, is not ſubject
3421. to the ſame Laws in theſe different Teleſcopes: *In catoptric Teleſcopes, the Light in the Spot, which is the Repreſentation of the Point, is ſuddenly weaken'd, as you recede from the Center, but not in others in the ſame manner.* Therefore we ſuppoſe the Teleſcopes mention'd in N. 3328, 3356, to be equally perfect. And the Compariſon will be founded upon the
* 3388. Rule deliver'd above *, by which it appears, that Teleſcopes of any kind, if they be equally perfect, amplify Objects equally, when the
† 3389. Apertures are equal; the Demonſtration of which is univerſal †.

3422. Let A be the Aperture, and L the Length of the dioptric Teleſcope given; a the Aperture, l the Length of the catoptric Teleſcope given; x and z the Lengths of two other Teleſcopes, of which the firſt is a dioptric, the other a catoptric Teleſcope, which are equally perfect with thoſe given, and agree among themſelves as far as relates to the Amplification, that is, have equal Apertures.

Then L, x : : A^2, $\frac{A^2x}{L}$ = the Square of the Diameter of the Aper-
* 3229.3231. ture of the Teleſcope x *.

And l^3, z^3 : : a^4, $\frac{a^4z^3}{l^3}$ = the Biquadrate of the Diameter of the
† 3378.3414. Aperture of the Teleſcope z †.

Theſe

Theſe Apertures are equal, therefore $\frac{A^4 x^2}{L^2} = \frac{a^4 z^3}{l}$.

The Quantities $\frac{A^4}{L^2}$ and $\frac{a^4}{l^3}$ are conſtant *, whatſoever the Teleſcopes given be. Let us ſuppoſe theſe to be as 1 to m, and we ſhall have $x^2 = mz^3$; now according to N. 3228 and 3256, let $A = 3$; $L = 30$; $a = 5$; it will be $m = 55\frac{5}{9}$, whence appears what was mention'd above.

We ought to take Notice here, that the Rule of N. 3383 does not very accurately agree with the Teleſcopes of N. 3328 and 3356, unleſs we increaſe the Diſtance of the Focus of the Eye Glaſs in the *Hugenian* Teleſcope $\frac{1}{30}$ of an Inch. *Hugens* determin'd the Diſtance of the Focus three Inches and three tenths (for there is an Error in N. 3228.) we ought to put three Inches and a third; then in theſe Teleſcopes the linear Amplifications are 108 and 180, accurately to one another as 3 to 5, that is, as the Diameters of the Apertures. 3423.

We have already obſerv'd that many Things muſt be alter'd in Teleſcopes according to Circumſtances *; among other Things we ſaid, that Glaſſes are not equally perfect; which muſt alſo be referr'd to Speculums; which, as well as Glaſſes, are not always made of equally fit Matter; all theſe Things we ſet aſide, as has been ſaid before.

CHAP. XVIII.

Of the Magic Lantern.

THERE are ſeveral other Machines conſtructed, in which, by Speculums and Lenſes joined, uſeful and pleaſant Spectacles are repreſented; the Explanation of which is eaſily deduc'd from what is ſaid before. 3424.

I ſhall make choice of one only, among others, to be explain'd, whereby Figures, painted on a ſmall Glaſs, are repreſented very large upon a white Plane. The Phænomenon is ſtrange enough, to deſerve a particular Explanation. The Machine is called a *Magic Lantern*, whereby it is repreſented; not indeed paſſed over by optical Writers, yet not ſufficiently treated of.

There is a Wooden Box, about a Foot and an half long, whoſe Breadth and Height is fourteen Inches; in this there is a concave Speculum S, of eight Inches Diameter, the Diameter of whoſe Sphere is a Foot and an half: This Speculum is applied to a Stand, which moves between Rulers along the Box. 3425. Plate 109. Fig. 1.

There is alſo in this a Lamp L, which is ſupported by a Wooden Stand, movable between Rulers at the Side of the Box, along it. 3426.

The

The Tube of the Lamp is prominent in ſuch manner, that the Center of the Flame anſwers to the Center of the Surface of the Speculum; this Flame conſiſts of four Flames, which mutually touching one another make a ſquare Flame, whoſe Side exceeds two Inches.

3427. There is an oblong Aperture in the upper Plane of the Box, which is cloſed with a Cover, moveable between Rulers; through this paſſes C, which (as appears in Fig. 3.) ſtands out above the Box about a Foot and an half high. This is moveable with it's Top; the aforeſaid Aperture remaining ſhut; which is plac'd ſo that it may anſwer to the Lamp.

3428. In the ſmaller Side of the Box there is a round Hole, of the Diameter of five Inches; in which there is a convex Glaſs V of the ſame Diameter: This is terminated on both Sides by a convex Surface, a Portion of a Sphere, whoſe Diameter is equal to one Foot: If an Axis of this Glaſs be conceived, it will be perpendicular to the Surface of the Speculum in the Center of it, as alſo to the Plane of the Flame through whoſe middle Point it paſſes.

This Hole is ſhut and open'd by means of a Board moveable between Rulers, which is mov'd by a Cylinder, ſtanding out of the Box at E.

3429. The Tube T anſwers to this Hole without the Box, whoſe Length and Diameter are about ſix Inches, in whoſe Extremity there is a Ring, in which a ſecond Tube *t* moves, of the Diameter of about four Inches, and Length of five or ſix Inches.

3430. In this ſmaller Tube there are two Lenſes; the firſt at the Extremity which is thruſt into the Tube T, and which is of the ſame Convexity with the Glaſs V, and of the Diameter of three Inches and an half; the ſecond Lenſe, which is three Inches diſtant from the firſt, is more plane and terminated by Portions of a Sphere of the Diameter of four Feet. Between theſe Glaſſes, at the Diſtance of an Inch from the ſecond, there is a Wooden Ring, with which the Tube is cloſed, a circular Aperture being left, of the Diameter of an Inch and a quarter.

The Objects to be repreſented are painted upon plane and thin Glaſs, which is moved without the Box near the Glaſs V, between this and the Tube T, the Picture being in an inverted Poſition. If theſe Glaſſes be round, they have the Diameter of five Inches; that they may be conveniently mov'd, they are faſten'd in a Frame of Wood, and three may be put into the ſame Frame. The Figures are alſo painted upon long Glaſſes, which are alſo put into

wooden Frames, and the Figures are repreſented ſucceſſively. Theſe Frames move between the Rulers R P, R P, which are join'd to the ſquare Board M, to which is faſten'd the Tube T. Plate 110. Fig. 1.

This whole Box is ſupported by a Stand, whereby it is fix'd at any Height, within certain Limits; the Planes *n*, *n*, are join'd to the Box, and are mov'd between Rulers along the Planes *m*, *m*, which make the Stand; in each of them there is a Slit; the Box is placed at the Height required, by Means of Screws fixed in the Stand, as *c*, and which move along the Slits. 3431. Plate 109. Fig. 3.

Experiment 1.

The whole Machine is plac'd at the Diſtance of fifteen, or twenty, or thirty Feet from a white Plane, which is different according to the Magnitude of this Plane; for this Diſtance ſhould exceed the Length of the Plane but a little. The Box is faſten'd at ſuch an Height, that the Glaſſes, in the Side of the Box, may anſwer to the middle of the Plane. The Lamp being lighted the Box is ſhut, and the Figures, painted upon the Glaſs, are repreſented upon the white Plane. By moving the Tube, in which the two Lenſes are, we diſcover the Poſition of it requir'd to make the Repreſentation diſtinct. 3432.

But the Diſpoſition of the Parts of this Machine, which are of uſe in exhibiting this Spectacle, muſt be more particularly explain'd.

The Parts are theſe, S S the Mirror; *l l* the Flame; this conſiſts of four Flames in the Line *l l*; V V is the Glaſs repreſented by V, Fig. 1; O O is the Picture in the ſmall Glaſs Plane; *a a* the large Lenſe; *d d* a planer Lenſe; *b b* the wooden Ring between the Lenſe; *f* the Aperture of the Ring, that is, the Hole in the middle of it. 3433. Pl. 109. Fig. 2.

All theſe Things being plac'd, as has been already explain'd, and as is ſeen in this Figure; the Rays, which proceed from the Point of the Picture O O in paſſing through the Lenſe *a a*, diverge leſs, and come to the Lenſe *d d* *, as if they proceeded from a more remote Point, out of which they go converging †, and are collected upon the Surface of the white Plane, and make a Picture of that Point of the Figure in the Glaſs ‡; the Figure in the Glaſs is enlighten'd both by Rays proceeding from the Flame *l l*, and by Rays reflected from the Mirror S S. 3434. * 3011. † 3011. ‡ 3058.

In order to make this Machine perfect it is requiſite, 1. That the Figure O O be enlighten'd as much as poſſible. 2. That it be enlighten'd equally in all it's Parts. 3. That all the Light by which 3435.

all the Points of the Figure are enlighten'd, paſs through the Lenſes *a a*, *d d*, to the white Plane, and ſerve to exhibit the Repreſentation. 4. Laſtly, that only this Light may go out of the Box, that the Repreſentation may not be leſs vivid by Means of the extraneous Light.

3436. The firſt Thing requir'd depends upon the Magnitude of the Flame and the Speculum, as alſo the Concavity of it; the more the Speculum is hollow'd, the nearer O muſt it be mov'd to the Flame, and the Rays are intercepted in a greater Number, and reflected; but Care muſt be taken, that the Speculum does not grow too hot, which is beſt made of Glaſs.

3437. But the Flame and Speculum being given, that the Picture may be enlighten'd as much as poſſible, and every where equally, the Flame and Speculum are ſo order'd, that the inverted Repreſentation of the Flame * may fall upon the Picture itſelf: But as the † 3312. Repreſentation of the Flame may be increas'd and diminiſh'd †, the Speculum and Flame are to be ſo plac'd, that the Repreſentation of the Flame may cover the whole Picture on the Glaſs, and not exceed it. For then the Picture is illuminated as much as poſſible by the reflected Light, and all it's Pictures are equally illuminated; the Light alſo falls directly upon all the Points of the Picture; which is ſenſibly equal; the Flame being brought near, this Light would indeed be increaſed, but the reflected Light would be diminiſhed; and this would be diminiſhed more than that would be increaſed.

* 3311.

3438. The Uſe of the Glaſs V V is to bend the Light with which the Picture O O is enlighten'd, before that comes to it, becauſe by the Inflection all the Light comes to the Lenſe, *a a*, and is of uſe towards the Repreſentation upon the white Plane.

3439. All the Light, which is of Service to this Repreſentation, paſſes through the Hole *f*; and the Rays proceeding from different Points mutually interſect one another; wherefore the Picture which is inverted upon the Glaſs, appears erect upon the white Plane; all the Rays, which are of no Uſe to make the Repreſentation, are intercepted by the Ring *b b*, that they may not enter into the Chamber and make the Picture leſs vivid. This Ring alſo intercepts the Rays, whereby one Point would be more enlighten'd than another, by which the Light, which is indeed equable enough, from what has been before ſaid, becomes ſtill more equable. Except the Ring *b b* be exactly in the Interſection of the Rays, it does a great deal of Harm.

EXPE-

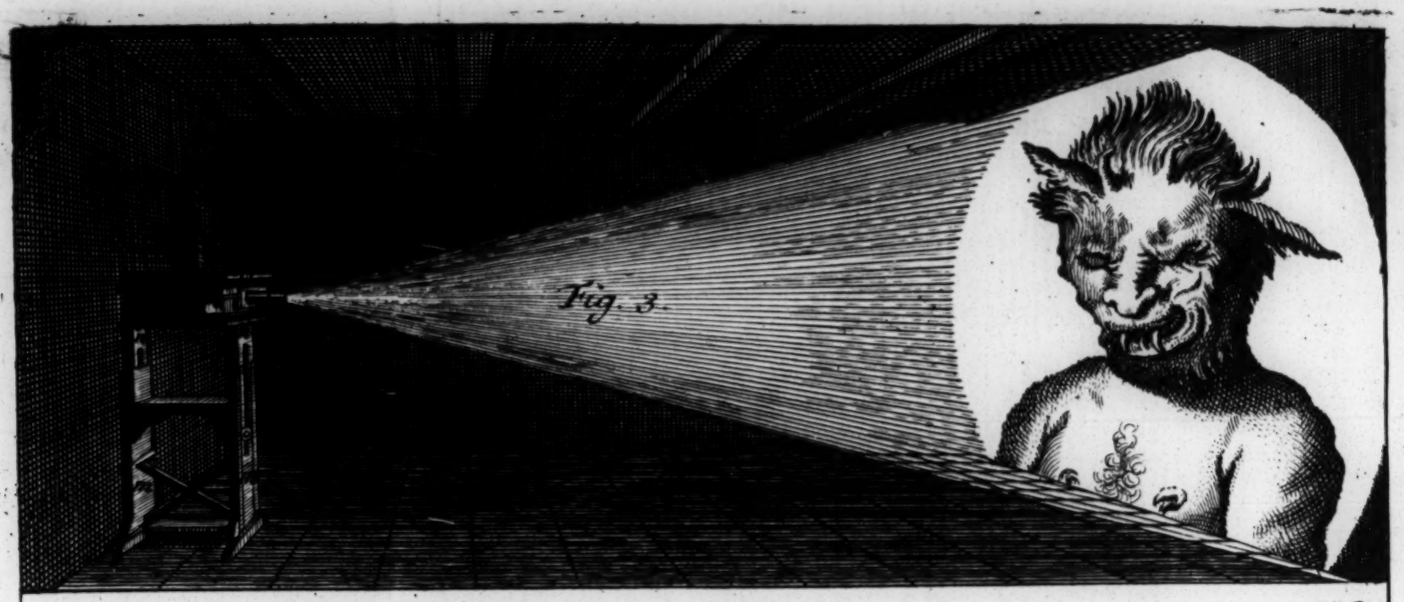


Fig. 3.

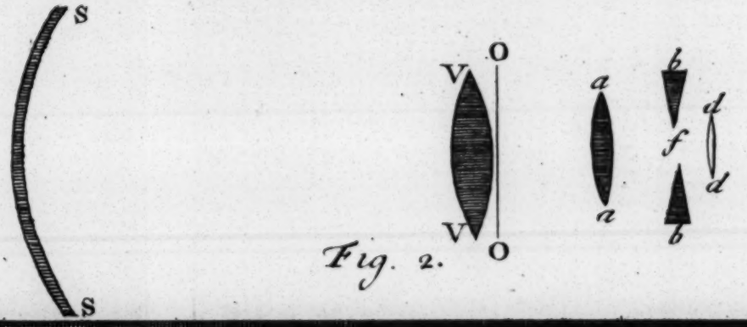
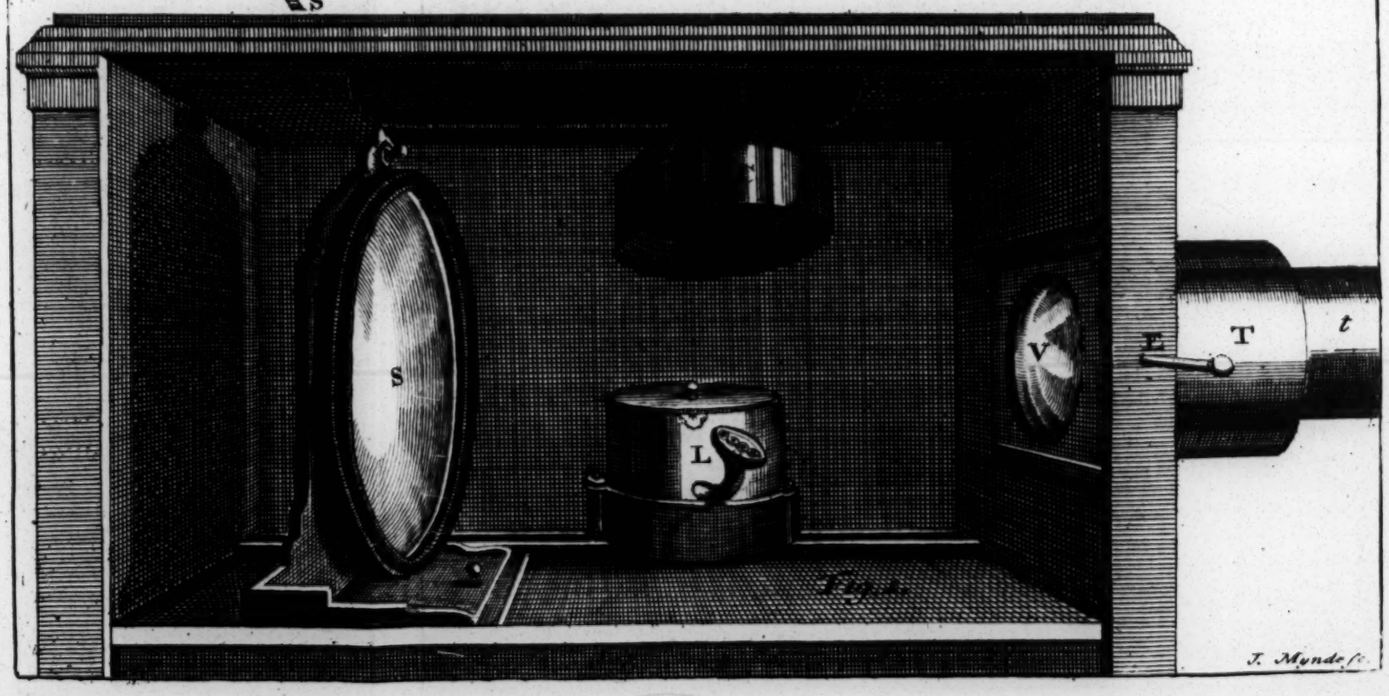


Fig. 2.



EXPERIMENT 2.

A Spectacle like that which we had in the firſt Experiment, is more conveniently and more diſtinctly repreſented in the Day Time, if the painted Figures be enlighten'd by Rays of the Sun. 3440.

A thick board H is applied to a Window, which ſtops a Hole in the Window-Shutter. At N there is an Aperture Q, which on the outſide is cover'd with thin Paper rubb'd over with Oil. 3441. Pl. 110. F. 1, 2, 3.

To the Board N is applied M with it's Tube T in ſuch manner, that the Interſtice between the Rulers R P, R P, may anſwer to the Slits L I, L I (one of which only appears in the Figure) in the Rulers H G, H G; that the Frames together with their Figures may be conveniently mov'd along the Aperture Q. We put into the Tube T what was mention'd above *, and what was repreſented in Fig. 3. in which the Section of the whole Machine through the Axis is delineated; C C is the oil'd Paper; O O the painted Glaſs; the reſt is explain'd above †, and mark'd with the ſame Letters here. * 3429. 3430. * 3433.

When the Sun's Rays fall upon the Paper, the Figures are ſtrongly illuminated, and are repreſented upon a white Plane, oppoſite to the Window, as in the laſt Experiment *. 3442. * 3432.

If the Paper be taken away, by reaſon of the Obliquity of the Sun's Rays, the Experiment does not anſwer well.

BOOK V.

PART IV. Of Opacity, and Colours.

CHAP. XIX.

Of the Opacity of Bodies.

3443. *THERE is no Body whoſe ſmalleſt Parts are not tranſparent:* Thoſe who often uſe Microſcopes do not in the leaſt doubt of this: There are ſome Parts of Metals, which, though very ſmall, do not tranſmit Light: Yet if they be divided in Menſtruums; that is, if they be divided into much leſſer Parts, they will become tranſparent.

3444. The leaſt Parts of all Bodies, that is, thoſe which ſeparate the ultimate or ſmalleſt Pores, are perfectly ſolid; of theſe we do not here ſpeak: But there are greater Parts formed by the Parts left by theſe Interſtices, which are join'd together, greater Interſtices remaining, and of which perhaps the greater Parts are formed, which Parts again may ſerve to form greater ſtill, and ſo the Parts and Interſtices between them have a farther Increaſe. When we ſpeak of ſmall Parts, we underſtand ſuch as are exceeding little, whoſe Pores do not exceed a certain Bigneſs; and by Pores we underſtand the greater Interſtices in the Pores of thoſe Parts which theſe Parts have between them.

3445. It is eaſily proved by an Experiment, that Light can paſs through moſt opaque Bodies.

EXPERIMENT I.

3446. If in a dark Room, into which the Sun's Light comes through a Hole, the Hole be cover'd by a thin Plate of Wood, the Light will paſs through it; the Hand, when applied to the Hole, does not intercept all the Light. But this Experiment does not prove that the Parts of opaque Bodies are perfectly tranſparent; for this only obtains in ſmall Parts.

Opacity does not ariſe, as is commonly imagined, *from the Stoppage of the Particles of Light by Particles of Matter*; for Light paſſes through all the ſmalleſt Parts of Bodies; nor is ſuch an Interception of Light of any Uſe in cauſing Opacity; for this it is required that the Light be reflected and deflected from a Right Line, in the Performance of which there is only required a Separation of two Mediums *. 3447. * 3247. 3260.

Let us ſuppoſe a Body conſiſting of very ſmall Parts perfectly tranſparent, ſuch as are the Particles of which Bodies are made †, ſeparated from one another by Pores; and that thoſe Interſtices are either void or fill'd with a Medium differing in refracting Force from that of the Particles; if Light enters ſuch a Body, it will every Moment fall upon a Surface ſeparating Mediums of a different refracting Force; and therefore it will undergo innumerable Reflexions and Refractions * in that Body; and it is ſo diſperſed in the Body, that it is eaſily all intercepted. Some of it often paſſes through, but the right lined Motion is entirely diſturb'd †. 3448. † 3438. * 3247. 3260. † 3445.

We ſee therefore that *Opacity depends upon the Pores*; for *if you fill the Pores with a Medium of the ſame refracting Force as the Particles of the Body themſelves*, the Light will undergo no Reflexion or Refraction in the Body, but paſs directly through; and *the Body will be tranſparent*. 3449.

Experiment 2.

If Paper be moiſten'd with Water, it becomes more tranſparent, for it fills the Pores, and differs leſs in refracting Force from the Particles of the Paper than Air does. Oil produces the ſame Effect. 3450.

Experiment 3.

Take a Piece of Glaſs, two Inches thick; take ſeveral Plates of the ſame Glaſs, which being laid upon one another, are not altogether quite two Inches thick; theſe, though they are ſmooth on each Side, will be leſs tranſparent, than a Piece of Glaſs, whoſe Parts all cohere together, becauſe of the Air that is between the Plates. 3451.

Experiment 4.

Take three Plates of ſuch Glaſs of which Speculums are made, placing them upon one another, whoſe four Surfaces, which are apply'd to one another, are made rough by rubbing Sand upon them; 3452.

them; the two outward Surfaces are ſmooth. Theſe Plates are opaque. If they be apply'd to Paper, upon which Letters are written, or upon which Figures are drawn, we perceive nothing of them. If the ſaid rough Surfaces be then anointed with Oil of Turpentine, and they be again applied to one another in the ſame manner, the Figures, which are cover'd with the Glaſſes, appear diſtinctly enough. But the Glaſs Plates are not perfectly tranſparent, the Oil of Turpentine does not exactly agree with the Glaſs in it's refracting Force; in the Paſſage of Light out of the Oil into the Glaſs the Sines of Incidence and Refraction are nearly as 60 to 59.

3453. But we ſee plainly how Bodies become tranſparent, in the firſt
* 2845. Experiment of the ſixth Chapter of this Book *, becauſe the Oil of Olives has the ſame refracting Force as the Borax, of which many Pieces may be uſed.

What has been ſaid about Opacity is farther confirmed, and put
3454. out of all Doubt by innumerable Experiments, by which *Bodies perfectly tranſparent become opaque by the Separation of their Parts*, without the Intervention of any opaque Body.

Experiment 5.

3455. Let any Liquid perfectly tranſparent, which may be changed into Froth, be agitated till it be full of Bubbles, it will immediately become opaque, becauſe the Interſtices are fill'd with Air.

Experiment 6.

3456. Turpentine and Water are tranſparent Bodies; but if they are mixed, they form an opaque Body.

Experiment 7.

3457. Water and Oil, by being mix'd, become opaque; though when ſeparate they are tranſparent.

Experiment 8.

3458. Glaſs, though never ſo tranſparent, when reduced to Powder, becomes opaque. So likewiſe it does when it is cracked.

3459. In all theſe Caſes we clearly ſee that Opacity is produced, becauſe there is a Medium of a different refracting Force between the tranſparent Parts; which alſo is obſerv'd in the Clouds, which are opaque, becauſe of the Air's Interpoſition among the Particles of Water.

If to theſe we add, what is ſaid in what follows, concerning the Colours of thin Plates; we ſhall have new Experiments, by which it is fully proved that Bodies intercept Light, becauſe they conſiſt of thin Particles, encompaſſed with a Medium differing from them in refracting Force. 3460.

Some opaque Bodies reflect a little Light, and the Light remaining is by the innumerable Diviſions, which it undergoes in the ſaid Reflexions and Refractions, extinguiſhed in the Body; ſuch are black Bodies; if there were any *Bodies perfectly black*, they *would reflect no Light at all*; for all Bodies, when no Light falls upon them, and they reflect no Light, appear black. 3461. 3462.

Other opaque Bodies appear of ſeveral Colours; ſome tranſparent Bodies are alſo ting'd with Colours: Whence theſe ariſe we ſhall now examine. 3463.

CHAP. XX.

Of the different Refrangibility of the Rays of the Sun, and their Colours.

BODIES appear differently colour'd, though they be enlighten'd by the ſame ſolar Rays, that are reflected by them: There are beſides ſeveral Phenomena of Light with regard to Colours, which muſt not be paſſed by.

In theſe three Things are to be obſerv'd: 1. The Rays muſt be examined, as they flow from the Sun. 2. Their Reflexion muſt be obſerv'd. 3. We are to enquire into the Make of the Surfaces of Bodies differently colour'd. 3464.

As to the Rays, the firſt Property to be here taken Notice of, is, that *all Sorts of Rays do not ſuffer the ſame Refraction under like Circumſtances.* 3465.

DEFINITION 1.

The Rays which undergo ſuch a different Refraction, are ſaid to have a different Refrangibility, and thoſe to be more refrangible, which are more inflected by Refraction. 3466.

DEFINITION 2.

Thoſe Rays are ſaid to be homogeneous which do not differ from one another in Refrangibility. 3467.

DEFINITION 3.

3468. *All thoſe are called heterogeneous, which are not equally inflected by Refraction under the ſame Circumſtances.*

3469. Let there be a Sun-Beam between A B and C D, made up of
Pl 110. an innumerable Number of parallel Rays; all theſe do not ſuffer
Fig. 4. an equal Refraction; for if they fall obliquely upon the Surface B D of the more refracting Medium, ſome of them are refracted between B E and D G, and are moved according to that Direction in the Medium; others are more inflected, and direct their Motion between B F and D H, in the Direction of thoſe Lines; nor can there be conceiv'd any intermediate Direction, along which ſome Rays do not move, in all the Points B and D: So that the leaſt Ray whatſoever is by Refraction, divided into innumerable other

3470. Rays; becauſe *every Ray, as it proceeds from the Sun, though never ſo ſmall, is heterogeneous, and conſiſts of innumerable Rays of all Degrees of Refrangibility.*

The parallel Rays aforeſaid, falling upon the plane Surface B D, are moved between B E and D H by Refraction; which Lines diverge more and more from each other, and, being continued, are more and more ſeparated; ſo that the Rays abovemention'd are

3471. diſperſed by Refraction. In N. 2859 *we have conſider'd the Rays as homogeneous*, as alſo every where *in the ſecond Part of this Book*; we have taken notice of a different Refrangibility in one Caſe only;

* 3222. the Difference of the Refrangibility in the Sun's Rays is ſo ſmall *, that it might have been neglected in what has been already ſaid. What happens to homogeneous Rays was alſo firſt to be examin'd; and what Alterations are to be made in the Propoſitions, by reaſon of the different Refrangibility, will eaſily appear to every Body.

3472. In order to make the different Refrangibility of Rays viſible, the Divergency aforeſaid muſt be increaſed; which will be done, when the Rays abovemention'd fall upon the Surface E H, which terminates the more refracting Medium, and ſeparates it from the leſs refracting Medium, and which makes any Angle with the Surface B D, but leſs than eighty Degrees, if Glaſs be uſed; but the Surface E H is ſo inclin'd to B D, that the Rays, which are more refrangible, fall more obliquely upon it than thoſe that are leſs refrangible; ſo that the former, in paſſing into the leſs refracting Medium, are more turned out of their Way, and diverge more from the others, for two Cauſes, the greater Refrangibility, and the greater Inclination. The leſs refrangible Rays continue their Motion between B E and D G, being refracted a ſecond time, they continue

continue their Motion between E I and G L, the others between F M and H N: In which Caſe if theſe Rays fall upon a Plane, at the Diſtance of fifteen or twenty Feet, the moſt and the leaſt refrangible Rays are ſenſibly ſeparated, and the whole intermediate Space is enlighten'd with Rays that have a mean Refrangibility; which is ſhewn by Experiments made with a triangular Glaſs Priſm through which a Ray is tranſmitted perpendicular to the Axis, and whoſe Sides are repreſented by the Lines B D and E H.

3473. But the Experiments that are of uſe here, are to be made in a dark Place, the Light being let in through a narrow Hole, as in the Experiments of the third Chapter of this Book; ſometimes we alſo make uſe of two Holes together. We have before ſaid what we muſt do when the Helioſtate is made uſe of *. We have alſo ſhewn how to proceed, when theſe Experiments are to be made without it *; but I will now explain it more clearly, * 2705.

3474. In Window-Shutters a ſquare Aperture is made whoſe Side is four or five Inches, which is clos'd by a Board, as T, which is moveable between Rulers, that it may be changed, becauſe ſeveral are required. Plate 110. Fig. 5.

3475. In this which is now exhibited there is a Hole whoſe Diameter is equal to three Quarters of an Inch; this is hollow'd behind, that the Object Glaſs of a Teleſcope may be put into it upon Occaſion. The Board T is alſo hollow'd a little before, that a thin round Plate of Braſs may be put into it, which is perforated, but not in the middle; and the Hole in this Plate anſwers to a Hole in T. To this Plate is joined another ſmaller concentric Plate *m*, which is moveable about a Center. In this there are ſeveral unequal Holes, which whilſt the little Plate is turn'd round paſs into *f* in ſuch manner, that Light may be let into the Chamber through a greater or leſs Aperture, at Pleaſure.

3476. When the Rays are to be let in through two Holes, we make uſe of another Board; in which there is a greater circular Aperture, which is cloſed by a braſs Plate; this turns about in that, that the Poſition of two Holes, which are in this Plate, may be alter'd.

3477. We may alſo make uſe of this Method, we cloſe the ſquare Aperture in the Window-Shutters by the braſs Plate T, whoſe fore-part is repreſented at *t*; in which we have mark'd the Magnitude *a*, *b*, *d*, *e*, of the ſaid Aperture. The Shutters are made hollow, to receive the Plate T, which is faſten'd by Means of the ſmall Buttons *h*, *h*, *h*. In the Middle there is a Hole *f*, and at the Angles there are four others *g*, *g*, *g*, *g*, whoſe Diameters Pl. 110. Fig. 6.

are three Quarters of an Inch; but which may be varied, and clos'd, by the Plates *m*, *n*, *n*, *n*, *n*, which turn upon the Centers *c*, *c*, *c*, *c*, *c*.

3478. When the Object Glaſs of the Teleſcope, which has been
* 3475. mention'd above *, is to be made uſe of, this is retain'd between the Screws *i*, *i*, *i*.

3479. In the following Experiments we make uſe of Priſms which
* 3249. turn about their Axis, ſpoken of above *.

3480. Such a Priſm A B is put upon a Stand, which is repreſented at
Pl. 110. S. The Priſm may be laid upon the Stand at different Heights,
Fig. 7. and faſten'd by Means of the Screw C.

3481. The Priſm may be alſo put into a vertical Poſition, then the prominent Part at B is put into the Hole *b*, and the Point C is put into the Slit *a*, and the Priſm may be faſten'd by the Screw.

3482. To this Stand is join'd the Board T going into the Groove *d*, *c*,
Pl. 110. and another like and oppoſite to this; the Face *t* of this Board is
Fig. 7. turn'd towards the Priſm. In this Board there are two Apertures D and E, which are cloſed by the Rulers *d*, *e*, which move between other ſmaller Rulers; thoſe Rulers are perforated at *f g*; and the Diameters of the Holes do a little exceed the eighth Part of an Inch. Sometimes two and alſo three Stands are requir'd; but in the others it is ſufficient, if the Priſm be fix'd at one Height only, and indeed that which is here repreſented; it is alſo ſufficient if two of the Stands have Boards.

Experiment 1.

3483. A Ray is let into the Chamber and directed upwards in ſuch
Pl. 111. manner, that it may make an Angle of about forty Degrees with
Fig. 1. the Horizon, but the Diameter of the Hole through which the Ray paſſes does a little exceed a quarter of an Inch. The Ray is
* 3480. tranſmitted through the Priſm P, which is laid upon the Stand S *,
† 2774. which ſtands upon the moveable Table M †, that it may be raiſed to the Height requir'd. The Ray is directed perpendicularly to the Axis of the Priſm, which is ſo plac'd, that the Ray may paſs through in the ſame manner as is repreſented in Figure 4, Plate 110; that is, that it may be equally inclin'd to each Surface of the Priſm.

3484. This Ray falls perpendicularly upon the white Paper T, extended upon a wooden rectangular Limb, which coheres with the Stand P,
* 2775. and may be raiſed and depreſſed and fix'd at the Height required *. But as the Ray, in paſſing through the Priſm, is diſperſed, it makes an oblong Image, which that it may be diſtinctly perceiv'd, the Paper

Fig. 3.

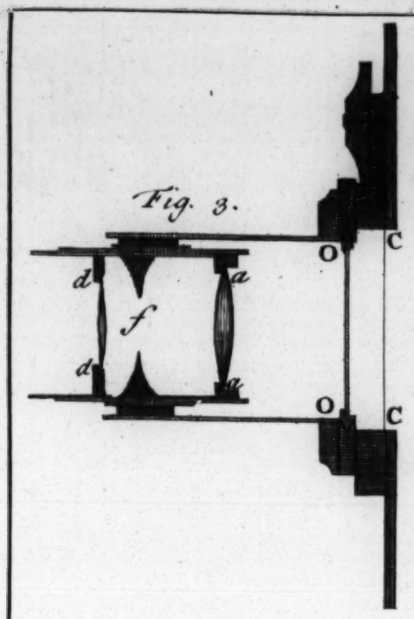


Fig. 2.

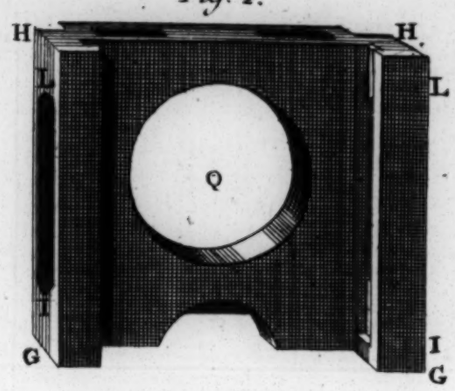


Fig. 1.

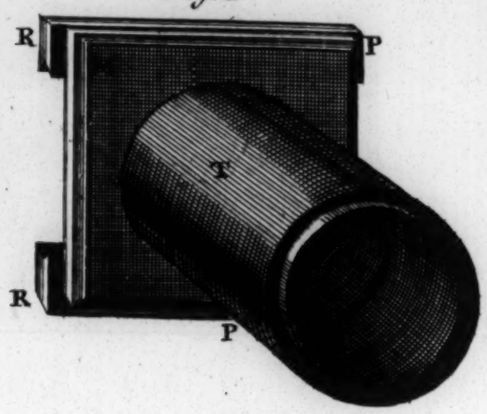


Fig. 4.

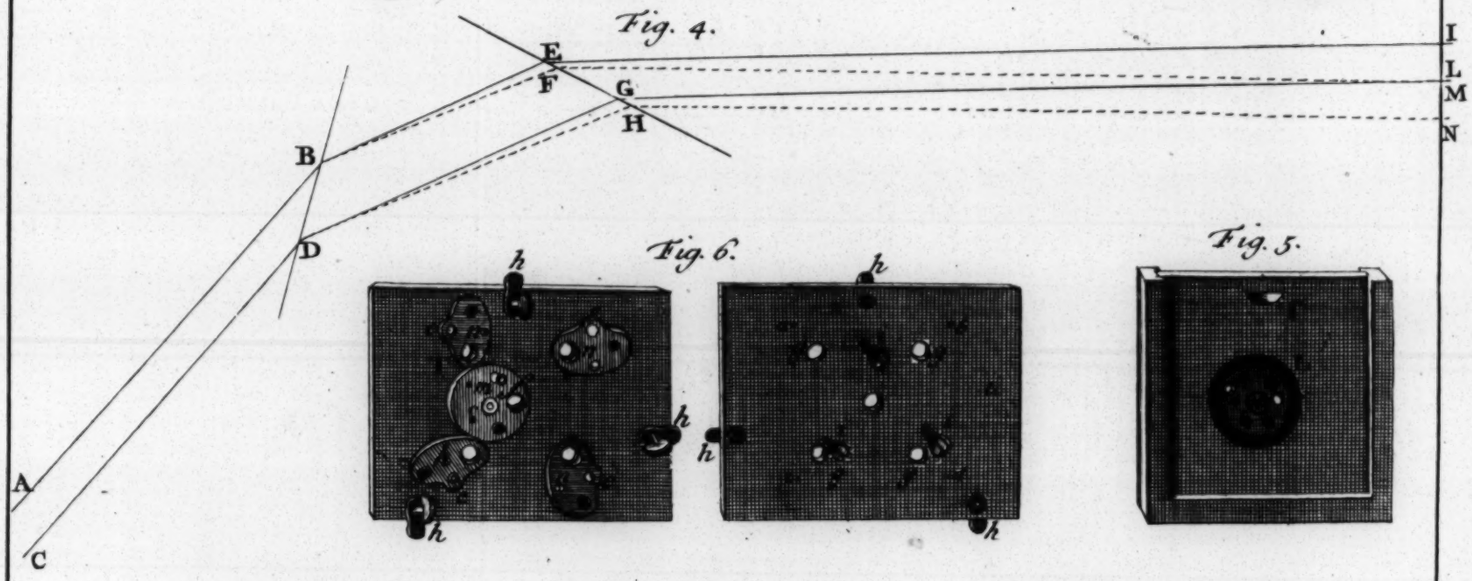


Fig. 6.

Fig. 5.

Fig. 8.

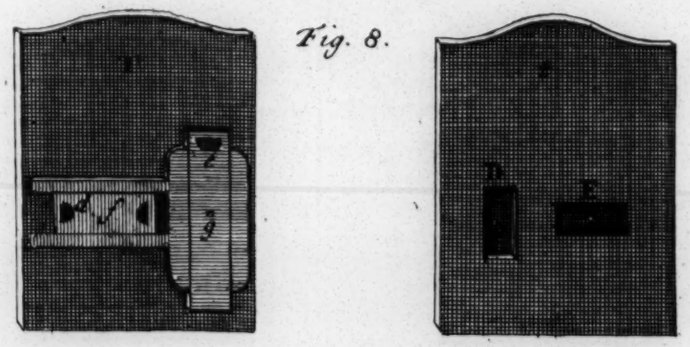
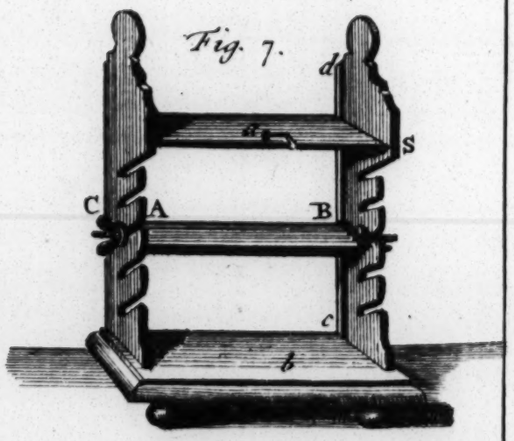


Fig. 7.



J. Mynde fc.

Paper ſhould be remov'd to the Diſtance of ſixteen or twenty Feet from the Priſm.

We determine the requir'd Poſition of the Priſm, and which was ſhewn above, if the Priſm be turn'd about it's Axis a little, in ſuch manner, that the Image may aſcend, which afterward deſcends, if the ſame Motion be continued; but the Priſm muſt be fix'd, when the Image comes to the greateſt Height, before it deſcends again. 3485.

How this oblong Image is made, is deduced from what has been exqlain'd before *, but I ſhall now explain it more diſtinctly. * 3472.

Let C be a Point of the Plane, parallel to the Hole, againſt which a Ray ſtrikes, which paſſes from the Center of the Sun through the Center of the Hole, which we ſuppoſe circular. All the Rays, which, proceeding from the other Points of the Surface of the Sun, interſect the firſt Ray in the Center of the Hole, and run againſt the Plane, make there an Image of the Sun *a*, *b*, *d*, whoſe Diameter, the Plane being remov'd ten Feet from the Hole, would exceed one Inch, and which would be increaſed in the Ratio of the Increaſe of the ſaid Diſtance. 3486. Pl. 111. Fig. 2.

The Rays, which paſs through all the Points of the Hole, give a like Image; and the Centers of them all are in a ſmall Circle equal to the Hole itſelf, for all the Rays proceeding from the Center of the Sun are taken for parallel. Therefore all the Images together make the Image A B D, which is weaken'd near the Limb, and whoſe Diameter exceeds the Diameter of the ſaid Image by a Quantity equal to the Diameter of the Hole.

If all theſe Rays were homogeneous, as they are in the laſt Experiment, equally inclin'd to the Surface of the Priſm, in the Ingreſs and Egreſs, the Direction of all of them would be only chang'd, and they would make a like white Image upon the Plane. But they are heterogeneous that paſs through the Priſm, and the moſt refrangible ones give the Image *a b d e*, which in the Experiment is more depreſſed; whilſt the leaſt refrangible Rays make the Image ABDE. The Rays of intermediate Refrangibility give intermediate Images, whoſe Centers take up the whole Line C *c*. Theſe Images jointly make the oblong Image repreſented in the foregoing Experiment; and except there were innumerable ſuch Images, the Image would not be terminated towards the Sides by Right Lines; but although this Image is terminated toward the Sides by Right Lines, yet the Terms are not diſtinct; becauſe the peculiar Images are not in the Form of a Circle *: But at the Extremities A and *e* the Light is * 3486. 3487. Pl. 111. Fig. 5.

weaken'd through the whole Semi-circle, and theſe Terms of the Image are confus'd.

But we eaſily have an Image diſtinctly terminated towards the Sides.

Experiment 2.

3488. The Object Glaſs of the Teleſcope beforementioned * is fix'd in
* 2706.3475. 3478. the Hole, and this Experiment differs from the laſt in this Circumſtance only. For Paper, or a white Plane, being plac'd at a juſt Diſtance, the Image is terminated diſtinctly.

3489. For if, the Priſm being taken away, the Image of the Sun falls upon the Plane, and the Plane be remov'd from the Glaſs to a Diſtance at which the Glaſs collects parallel Rays proceeding from all Points of the Sun's Diſk, there will be given a round Image of
* 3060. the Sun, as we have ſeen of other Objects *. When the Rays paſs through the Priſm, the Image is made oblong from innumerable Images well terminated.

3490. What has been ſeen concerning the different Refrangibility in Glaſs is in the ſame Manner obſerv'd in other Mediums.

Experiment 3.

3491. The Box P is made of three Glaſs Plates, whoſe Bottom is of
Pl. 111. Fig. 4. Braſs; this is conſtructed, as has been ſeen above *; the Angles, which the Planes make, are of 50, 60, and 70 Degrees.

* 2759. Any Fluid is pour'd in, as Spirit of Wine, Oil of Turpentine, *&c.* and a triangular Priſm is made of the Matter pour'd into the Veſſel, whoſe Figure this puts on.

3492. We have Occaſion for a Ray of the Sun let into a dark Place, in this Experiment, as in the foregoing ones; but it's Direction muſt be horizontal.

This is tranſmitted through the Priſm, or Box mention'd, which if it be empty, the Light paſſes through in a ſtrait Line, but if it
* 3472. contains a Fluid, it is bent, as has been ſeen above *. The Priſm is diſpoſed in ſuch manner, that the Light may be equally inclin'd
† 3485. to each Surface through which it paſſes †; and the Light, if it falls upon a vertical Plane plac'd at the Diſtance of ſixteen or twenty Feet from the Priſm, will give an oblong Image, as in the foregoing Experiments, but horizontal, whoſe Length will be different, according to the different Angle, which the Surfaces make, through which the Light paſſes, and according to the different refracting Force of the Fluid, contain'd in the Priſm.

EXPERIMENT 4.

Let there be a Spectator at the Diſtance of ſixteen or twenty Feet looking at the Hole, through which the Light is let into the Chamber, that appears round; if the Obſervation be made through a Priſm, in ſuch manner, that the Rays proceeding from the Hole, come to the Eyes, after Refractions, like thoſe which the Light undergoes in the mention'd Experiments, the Hole will appear oblong. The Poſition of the Priſm is found, if, this being put into a horizontal Poſition with the Edge uppermoſt, in ſuch manner, that the Hole be raiſed, it be turn'd about it's Axis a little, with which Motion the Image of the Hole aſcends and deſcends, and the Priſm be kept in the Poſition, in which the Hole appears raiſed leaſt of all. The Priſm may alſo be put into a contrary Poſition. 3493.

This Experiment, as well as the foregoing, proves the different Refrangibility of Rays; for, by homogeneous Rays of any Refrangibility, the Hole appears remov'd out of it's Place, but circular.

The Rays, which undergo a different Refraction, enter the Eye in different Directions, and different Images are given, which join'd make an oblong Image, which is really ſeen.

Beſides the different Refrangibility of the Rays, the foregoing Experiments alſo ſhew another remarkable Difference between the Rays. 3494.

The different Refrangibility of the Rays is join'd with a different Colour; and all the Rays, as they are more or leſs bent by Refraction, have a Colour peculiar to themſelves. 3495.

With Regard to Colours it muſt be obſerv'd, as has been already obſerv'd * concerning other Senſations, that they are Perceptions, which have nothing common with the Rays, whereby they are excited; therefore we muſt give a Definition, what we underſtand by colour'd Rays, and colour'd Objects. 3496. * 2310.

DEFINITION 1.

An Object is ſaid to be ting'd with that Colour whoſe Idea is excited in the Mind by Rays reflected from the Object. 3497.

DEFINITION 2.

Homogeneous Rays which ſtrike againſt the Retina and excite in the Mind an Idea of any Colour, are call'd Rays of that Colour. 3498.

We ſay that Rays excite the Idea; that is, that Rays move the Fibres, and that when this Agitation is given, the Idea is preſent to the Mind. 3499.

We

3500. We find the Colours of Rays immediately in *the oblong Image of the Sun* often mention'd; for this Image *is ting'd with different Colours.*

3501. *The Rays that are leaſt turn'd out of the Way by Refraction, are* Pl. 111. *red Rays; the reſt of the Colours follow in this Order, orange, yellow,* Fig. 3. *green, blue, purple, violet,* the Rays of which laſt Colour have the greateſt Refrangibility.

3502. The oblong Image of the Sun, as has been ſaid, is made of in- * 3487. numerable round Images *: If the Diameters of them be diminiſh'd, which is done by intercepting the Rays of the Sun in ſuch manner, that thoſe only may paſs through the Priſm, which come from a ſmall Part of the Surfaces of the Sun, the Centers of the peculiar Images making the oblong one are not alter'd; therefore the Length *a b* of the Image between the parallel Lines is not alter'd. And this only would remain, if the Breadth of the Image ſhould be infinitely ſmall, and this Length only were to be conſider'd in determining the Limits of the Colours in the Image. Theſe are mark'd in the Figure by the Letters *a, b, c, d, e, f, g, h,* and the Number wrote againſt every Colour denotes the Space taken up by it in the Image, the whole Length of the Image being divided into 360 Parts.

3503. *The Rays in the oblong Image* are indeed ſeparated; nevertheleſs every where many peculiar circular Images are confuſed, and they *are no where perfectly homogeneous.*

3504. *When the Breadth of the Image is diminiſhed* by the Method juſt * 3502. ſhewn *, all the Circles become ſmaller and are confuſed by a ſmaller Number, and thoſe, which are confuſed, differ leſs in Refrangibility; wherefore *in the* whole *Image the Rays are more homogeneous, and the Colours more perfect*; and likewiſe weaker.

3505. The Colours in the Image are alſo more perfect, the ſmaller the Hole is, through which the Rays are let in; becauſe the Number * 3486.3487. of the Images, which are every where confuſed *, is diminiſh'd, and they have a different Refrangibility; the Image is alſo weaken'd.

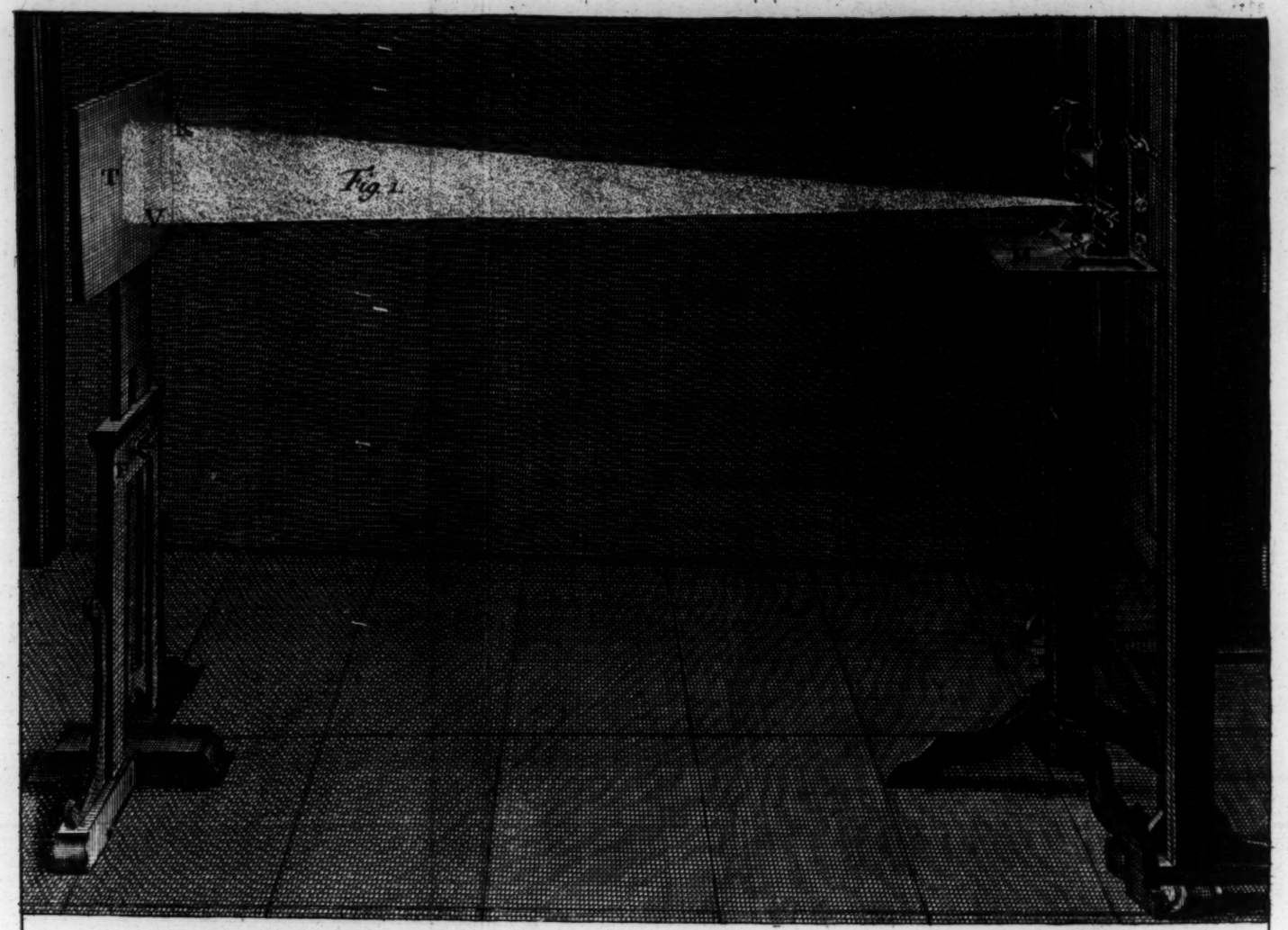
Nevertheleſs the Colours become but a little more perfect by this * 3502. Method, the firſt is to be prefer'd *.

3506. But if we would have the Colours more lively, and at the ſame Time more homogeneous, we have them in the following Experiment.

Experiment 5.

3507. Rays proceeding from the Sun are let into a dark Chamber through Pl. 112. a Hole, whoſe Diameter is equal to about the eighth Part of an Fig. 1.

 Inch;



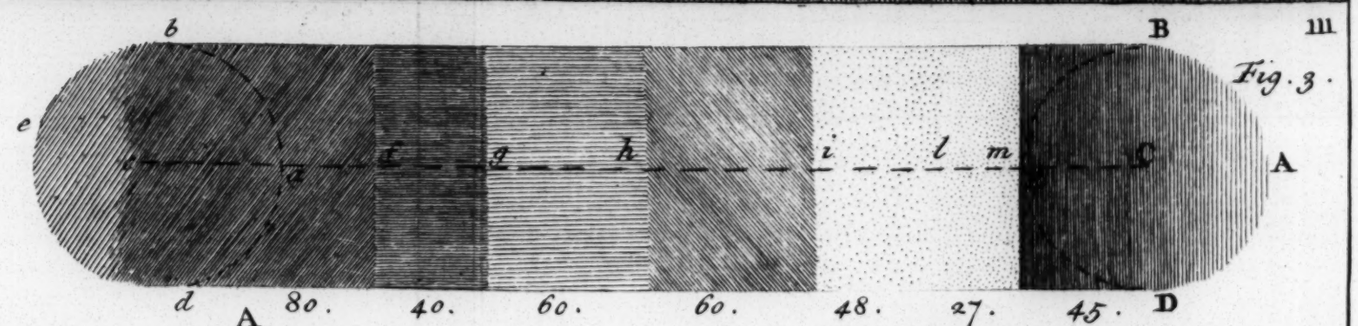


Fig. 3.

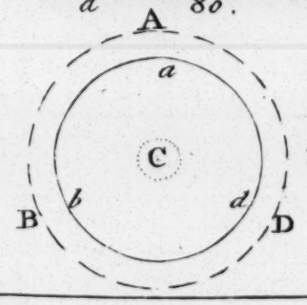


Fig. 2.



Fig. 4.

T. Mynde sc.

Inch; the Direction of theſe is horizontal, and at the Diſtance of eight Feet from the Hole they fall upon the convex Lenſe L, which collects parallel Rays at the Diſtance of four Feet; if theſe Rays run againſt a white Plane at the ſame Diſtance of eight Feet from the Lenſe, they will give an Image of the whole equal to it *. * 3035.3045.

But if the Rays behind the Lenſe be intercepted by the vertical 3508.
Priſm P *, they are bent, and diſperſed †, and make the colour'd * 3481.
Image R V; by turning the Priſm about it's Axis the Poſition of † 3484.
the Priſm is ſought, in which the Rays are leaſt bent, and faſten'd ‡,‡ 3485.
the Paper T * is plac'd, that the Light may fall upon it perpen- * 3484.
dicularly; and it is removed till the Image be circular.

This Image has but a ſmall Breadth, becauſe it conſiſts of Images 3509.
equal to that mention'd *; it is vivid, and as the homogeneous * 3507.
Images are confuſed in a ſmaller Number; the Light is every where leſs hetrogeneous than in the foregoing Experiments.

We have an Image equally pure, but more broad, if the Light 3510.
paſſes through a vertical Slit, above an Inch high, and whoſe Pl. 112.
Breadth is equal to the Diameter of the Hole which has been made Fig. 2.
uſe of in the Experiment. The Slit may be alſo narrow'd more, and then the Light is every where more homogeneous in the Image, which now makes a Parallelogram, whoſe Breadth is equal to the Height of the Slit. If this Slit have the Figure of an Iſoſceles Triangle 3511.
whoſe Baſe compar'd with the Height is ſmall, the Image throughout it's whole Length is more vivid near one Side, and is weaken'd towards the other; becauſe the Slit is narrow'd towards that Part, through which the Rays paſs: Therefore the Light is alſo more homogeneous, in the Ratio, in which it is weaken'd.

The Demonſtration, before given *, *concerning the conſtant Ratio* 3512.
between the Sines of the Angles of Incidence and Refraction, muſt be * 2809.
referr'd to all homogeneous Rays; for it is not confin'd to any certain Degree of Refrangibility; but this Ratio varies, according to the different Refrangibility; as clearly follows from the Experiments of this Chapter.

But that *Refrangibility and Colour in all Rays are entirely un-* 3513.
changeable; that is, that they are not alter'd by any Refractions, Reflections, or Permixtions, plainly appears from Experiments to be ſhewn in the three next Chapters.

CHAP.

CHAP. XXI.

That Rays are not alter'd by Refraction.

3514. WE ſhall now demonſtrate by Experiments, that *the different Refrangibility of Rays is inherent in them, as alſo their Colour*, and that theſe Qualities do not depend upon a refracting Medium, from which Experiments it will appear; that *the Rays,*
3515. *which in one Caſe undergo the greateſt Refraction, are moſt turn'd out of their Way in any other Refraction whatever,*

EXPERIMENT I.

3516. A Ray, as in the firſt Experiment of the laſt Chapter, is let
Plate 112. through a Priſm, this is diſperſed, and divided into many Rays,
Fig. 3. which would make an oblong Image, if they fell upon a white
* 3484. Plane *; but they are intercepted by the vertical Priſm C D, plac'd at any Diſtance from the firſt Priſm; but the leſs the Diſtance is, the more ſenſible is the Experiment.

The Rays in paſſing, through this ſecond Priſm, are bent ſidewiſe, and the Priſm being mov'd, till the Deflection is the greateſt of all, let it be fix'd; and let the Rays fall upon white Paper perpendicularly.

3517. The Rays are now refracted by the ſecond Priſm in the ſame manner, as by the firſt, but they are not diſperſed in the ſame manner, which would give a ſquare Image; but this is inclin'd at R V, the Rays being turn'd out of their Way moſt at V, as in the Refraction through the firſt Priſm.

3518. There is alſo another different Refraction of the Rays, not depending upon the Rays, but the Medium. Chryſtals and tranſparent Flints, though I can't ſay all, have this wonderful Property, that they divide in Refraction every homogeneous Ray into two; which Separation is different not only in different Bodies, and in different Inclinations of the Rays; but it is alſo different in the ſame Body, and the ſame Inclination, according to the different Poſition of the refracting Surface, and the refracted Ray, with reſpect to the Vein of the Stone; but neither the Colour nor Refrangibility are alter'd by ſuch a double Refraction, and Diviſion of Light.

EXPE-

EXPERIMENT 2.

This Experiment was made with a very pure Priſm, ſent from *England*, made of a *Braſil* Pebble. 3519.

This Priſm is equi-angular, and the firſt Experiment of the laſt Chapter being repeated with this Priſm, inſtead of the Glaſs Priſm, and this being plac'd in ſuch Manner, that the Axis might be horizontal; I obſerved three different Phenomena, according to the different Angle, that was upwards: A double Refraction was always diſcover'd, and two oblong Images were perceiv'd; but they were not ſeparated.

In the firſt Poſition of the Priſm the upper Part of the Image was painted with a pure red Colour, the lower with a violet Colour, in the whole intermediate Space, it appear'd that there are the ſame Colours, which we had before, but theſe were confuſed and mix'd together, ſo as they ſhew'd, that there were two colour'd Images, which did not agree. 3520.

In the ſecond Poſition of the Priſm, the Images did leſs agree, and the red Colour of the upper Image was ſeparated more, as likewiſe the violet Colour of the lower Image, and that Image was longer. 3521.

In the third Poſition of the Priſm the Image was extended very much, and they were both ſeparated more, ſo that the red Colour was entirely raiſed above the lower Image, and likewiſe the orange Colour, and part of the yellow Colour of the upper Image; whereby it happen'd alſo, that the violet Colour, and Part of the Purple, of this Image was ſeparated; the reſt of the whole Image was very much confuſed. 3522. Plate 112. Fig. 4.

The Priſm remaining in this Poſition, I tranſmitted Rays, going out of this, through the vertical Glaſs Priſm, as in the laſt Experiment *. By this Refraction they were inclin'd, and quite ſeparated. 3523. * 3516.

Theſe Images were parallel, and the Colours in the vertical Lines correſponded, and indeed in ſuch manner, that it appeared, that the red Colour of each Image was the leaſt bent of all in the ſecond Refraction, and equally in both Images. So alſo the two violet Colours had the ſame Refrangibility, and the greateſt of all. 3524. Plate 112. Fig. 5.

Although it is manifeſt enough from theſe Experiments, that Colour and Refrangibility are not alter'd, which is alſo confirm'd by many Experiments, hereafter mention'd; nevertheleſs I will add one Experiment more, which has been made by many without Succeſs, but which always ſucceeds, when due Caution is uſed. 3525.

EXPERIMENT 3.

3526. A Ray of Light is tranſmitted through the Priſm, as in the firſt
Plate 113. Experiment in the laſt Chapter ‡; but the Hole, through which
Fig. 1. the Light enters, is greater, and it's Diameter exceeds half an Inch:
‡ 3483. The Light, whilſt it goes out of the Priſm, falls upon the Surface
* 3482. of the Board T *, which intercepts the Rays, thoſe only being left,
† 3482. which go through the Hole *g* †. Theſe are not yet ſeparated; becauſe this Hole is at a ſmall Diſtance from the Priſm: Yet they are diſperſed, and the oblong Image R V, falls upon the Board
‡ 3482. join'd to the Stand of the ſecond Priſm ‡, at the Diſtance of ten or twelve Feet: Which Stand is ſo plac'd that the Hole g, which correſponds with *g*, is in the Image itſelf, and ſome of the Rays paſs through it, which fall upon the ſecond horizontal Priſm, by whoſe Refraction they are directed downwards or upwards, as in this Figure, and fall upon the white Paper. By moving the firſt Priſm a little about it's Axis, the Rays of all Colours go through the Hole g ſucceſſively, and are refracted by the ſecond Priſm.

3527. In this ſecond Refraction there is no Diſperſion of the Rays; the Images, when the Paper is inclin'd, ſo that the Light falls upon it perpendicularly, is round, and of one Colour; namely of that, which paſſes through g; the Refrangibility alſo in this Caſe is not alter'd, and the Spot S changes it's Place in ſuch manner, whilſt the Colour is alter'd, that it appears that the red Rays are refracted leaſt of all, the violet Rays moſt of all.

3528. This Experiment may be varied, and made with vertical Priſms, in this Caſe, the Ray, which falls upon the firſt Priſm, muſt be ho-
* 3482. rizontal; then the Holes *f* and f * are to be made uſe of, which are in Plates that may be moved horizontally.

3529. The firſt Priſm remaining alſo, and the Light being tranſmitted through the Hole *g*, a ſecond Priſm may be plac'd vertically, and the Light, which paſſes through the Hole f, may be bent ſideways. The Event of the Experiment is always the ſame.

3530. We tranſmit Light through two narrow Holes, that it's Direction may be well determin'd, and all the Rays may follow the ſame Direction. The Hole, through which the Light is let in, muſt, for this Reaſon, be larger than in the foregoing Experiments, that the
3531. Light, which paſſes through *g*, may not be too weak. Thoſe ſmaller Holes are made uſe of, which are in the Plates that may be mov'd perpendicular to the Direction of the Axis of the Priſm, that the Holes may anſwer exactly to the Priſm. But as the Event of this

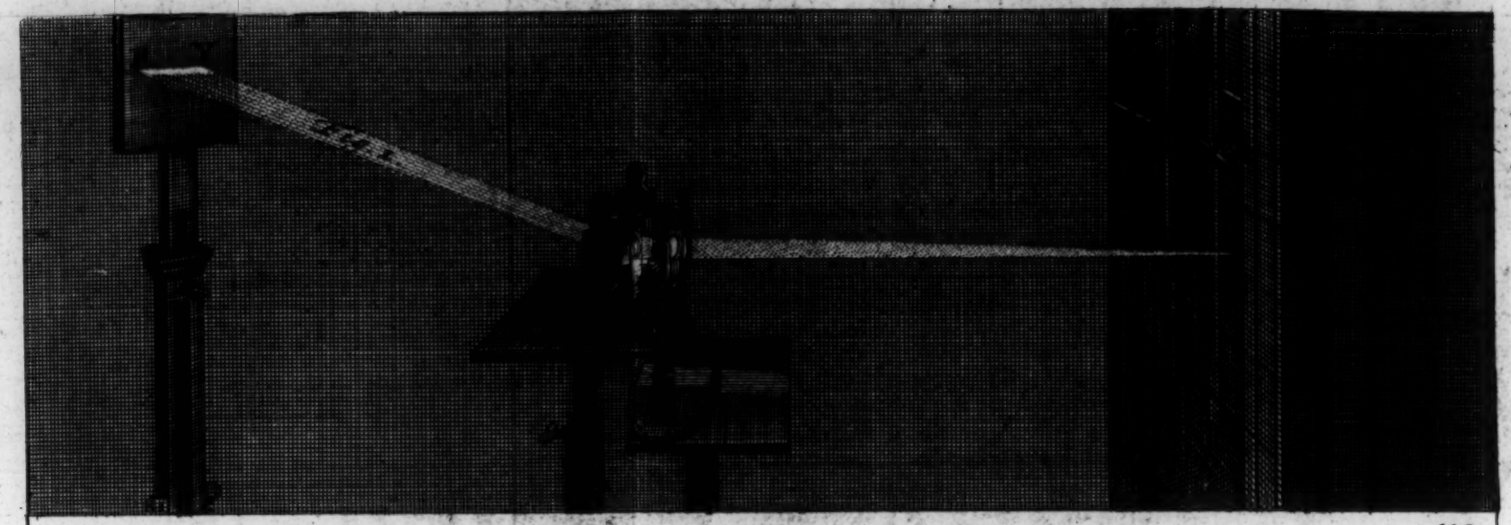




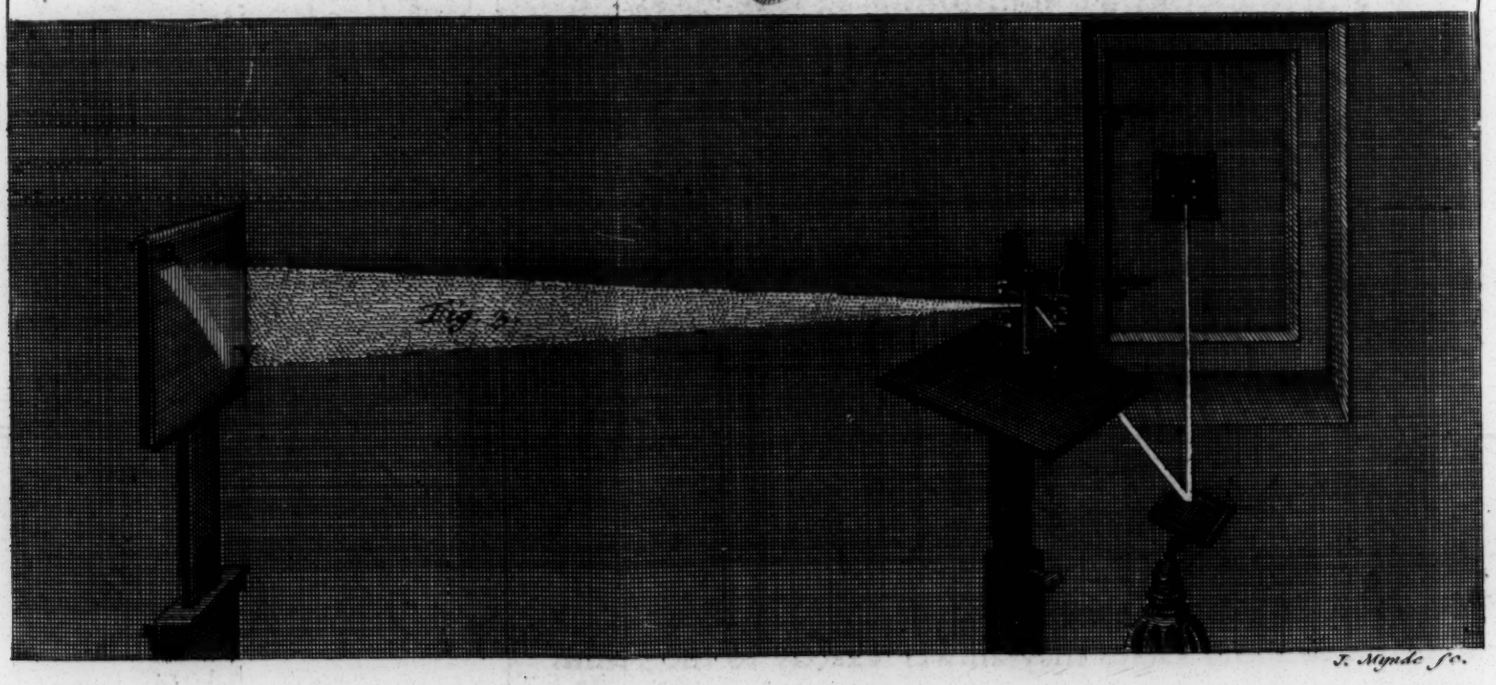
Fig. 2.



Fig. 4.



Fig. 5.



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this Experiment is not always the ſame, and *Mariotte*, who was well verſed in phyſical Experiments, affirms, that after the ſecond Refraction of any Ray, the Colours appear different again; ſomething muſt be mention'd, and I muſt ſpeak diſtinctly of the Cautions that are to be obſerv'd. 3532.

If with the Rays of any Colour, a ſmall Quantity of Rays of different Colours be mixt, the Colour is not alter'd thereby as to Senſe: becauſe the vivid Light hinders the weak Light from being ſenſible; but if ſuch Rays, which appear to the Eye homogeneous, paſs through the Priſm, they are ſeparated, and the Colours then become ſenſible: therefore unleſs the Rays be homogeneous that fall upon the ſecond Priſm, the Experiment neceſſarily ſucceeds as it is deſcribed by *Mariotte*; but who does not ſee that nothing can be concluded from ſuch an Experiment if the Event be the ſame as that which we have deſcribed above *, the neceſſary Cautions being obſerv'd? 3533. * 3527.

The Priſms that are to be made uſe of, eſpecially the firſt, muſt be of pure Glaſs, otherwiſe there are Reflexions of the Rays in the Priſm itſelf, and in the going out the heterogeneous Light is every where mixt with the homogeneous Light, which, whilſt it is ſeparated, diſturbs the Experiment. 3534. 3535.

Care muſt be taken alſo, that no Light enters the Chamber, except the Ray mention'd in the Experiment; for if any ſuch Rays be mixt with thoſe, that make the Image, the Experiment cannot anſwer well.

We muſt alſo take care that the Experiment be not made when the Sky is not clear enough; for then there are many Rays among thoſe, that proceed directly from the Sun, which follow different Directions; which chiefly happens, when there are Clouds towards the Sun, which reflect Light vivid enough. 3536.

CHAP. XXII.

That the Rays are not alter'd by any Reflexion.

WE prove by Experiments that the Rays are not altered by Reflexion. 3537.

EXPERIMENT I.

An oblong Image of the Sun being given, tinged with homogeneous Colours *, let the different Colours of it fall ſucceſſively upon the Surfaces of different Bodies, for Example, upon that of 3538. * 3484. 3500.

Cloth of different Colour, or Silk, or of any other Body; or we may take any painted Bodies, or the Powders themſelves, that Painters make uſe of; in all theſe Caſes the Rays in Reflexion keep their own Colour; the red Rays remain red, whether they are reflected from a red Body or a blue one; but the Colour is more obſcure and dark, when the Colour of the Rays does not agree with the Colour of the Body, notwithſtanding it is not alter'd.

A STAND *for the two* PRISMS.

3539. Upon the wooden Stand P two wooden Pillars are plac'd, about
Plate 114 a Foot high, which ſupport the tranſverſe Piece of Wood M M.
Fig. 1. The lower Priſm A B is laid upon the ſmaller Pillars G G *, which
* 3249. turns about it's Axis, and is faſten'd by a Screw at *c*.

3540. The other Priſm E F † is like the former; this has a Handle
† 3249. H; *n* paſſes through this, which makes one End of the Axis, through a Hole at the End of the Handle; the other End *o* goes into an Inciſion, tending obliquely downwards; and the Priſm is faſten'd by the Screw *m*; the Handle is ſupported together with the Priſm, by Means of the Copper Plate L, which may be rais'd and let down, and which is retain'd by the Screw *n*.

3541. The Handle H is join'd to the Plate L in ſuch Manner, that the Priſm, it's horizontal Poſition being kept, together with it's Handle, may be turn'd about, a vertical Line paſſing through *p*; and the Handle is faſten'd by Means of the Screw I. We ſhall call this laſt Motion the Converſion of the Axis of the upper Priſm.

EXPERIMENT 2.

3542. We let Light into a dark Chamber through two Holes *, in the
Plate 113. ſame Manner as through one in the firſt Experiment of the twen-
Fig. 2. tieth Chapter. The lower Ray is tranſmitted through the lower
* 2705. 3476. Priſm, and gives an oblong Image; the upper Priſm is rais'd, by
3477. moving the Plate *l*, or let down and faſten'd at that Height, that another Ray may fall upon it; by Help of this we make a ſecond
* 3541. Image, which, by turning the Axis of the Priſm *, we diſpoſe in ſuch Manner as to join the Images ſideways; then, by turning one of the Priſms about it's Axis, we depreſs one Image in ſuch Manner, that the red Colour of it may anſwer to the violet Colour of the other Image. The Paper being removed which covered the
† 2775. wooden Rectangle †, the upper Ruler L L of the Rectangle, is to be

be placed in ſuch Manner, that the ſaid Spots, the one red R, and the other violet V, may fall upon the Middle of the Ruler. This is white in that Place, and every where elſe black, with the reſt of the Rectangle and the Stand.

Now if a Spectator at the Diſtance of ſixteen or twenty Feet beholds theſe Spots R and V, attending to that which has been ſhewn above *, he will ſee the violet Spot at *u*, and the red one leſs removed out of its Place at *r*; ſo that there is no Alteration in the Colour's Refrangibility, though the Rays are reflected. 3543. * 3493.

The Parts of the Images which paſs above and below the Ruler L L, muſt fall upon the black Plane, that they may not diſturb the Experiment. 3544.

But this Experiment anſwers beſt, when there is another dark Chamber near at Hand, into which theſe Rays may penetrate: If then the Spectator beholds theſe Spots a little obliquely, none of the uſeleſs Light can be reflected to him. 3545.

Experiment 3.

This Experiment ſucceeds beſt of all alſo, if there be two Chambers ſeparated only by a Door, and they be both dark; then the Priſm being placed at the Diſtance of ſixteen or twenty Feet from the Door, the Rays are ſeparated, that an oblong Image of the Sun may be made *, which in the other Chamber falls upon the Paper at R V, at the Diſtance of upwards of thirty Feet from the Priſm. 3546. Plate 114. Fig. 2. * 3483.

Upon this Paper T are drawn black Lines parallel to one another, about the ſixteenth Part of an Inch broad, which are enlightned by the ſaid oblong Image of the Sun, according to the Length of which, the Lines are diſpoſed; there is moreover a convex Lenſe of five or ſix Inches Diameter, ſuch as has been uſed above; or if this be not ſo convenient, we make of one more convex, which collects the red Rays proceeding from a radiant Point ſix Foot diſtant from the Glaſs, at an equal Diſtance; if this Lenſe be at the Diſtance of ſix Feet from the ſaid Image, the Parts of the Lines, which are in the red Colour, are repreſented upon the Paper, by Rays collected by the Lenſe, at the Diſtance of ſix Feet alſo, exactly in the red Image, but the Paper muſt be moved nearer about three Inches and an half, that the Parts of the Lines, illuminated with a purple Colour, may appear diſtinct in the Image of the ſaid Colour: the intermediate Colours give their Images at intermediate Diſtances; the violet Colour is ſo weak, that the Lines in it cannot be repreſented. This 3547. * 3507.

3548. This Experiment anſwers alſo, though there be not a ſecond dark Chamber; but then we ought to prevent the extraneous Light, which enters into the Chamber through the Hole, from making the Repreſentation of the Lines too weak, by means of a Curtain or any other Way, if we do not make uſe of the Helioſtate.

3549. Therefore this Experiment is a Confirmation alſo, that the Colour of the reflected Rays is not alter'd by a new Refraction through a Lenſe; as likewiſe that the moſt refrangible Rays are inflected

3550. more than others, in paſſing through the Lenſe: This laſt Experiment likewiſe proves, that *the different Refrangibility of the Rays is the Reaſon that Teleſcopes are not perfect*; for the Rays proceeding from Points at an equal Diſtance, are collected at various Diſtances from the Lenſe, according to their different Colour; whence alſo the Repreſentation of the Points are at unequal Diſtances from the Eye-glaſs, which therefore cannot all be ſeen perfectly through it.

3551. With Regard to the Reflection of the Rays, that the *Rays are in general more eaſily reflected, which have a greater Refrangibility*, for the greater the Refraction of the Rays is, the leſs Obliquity is

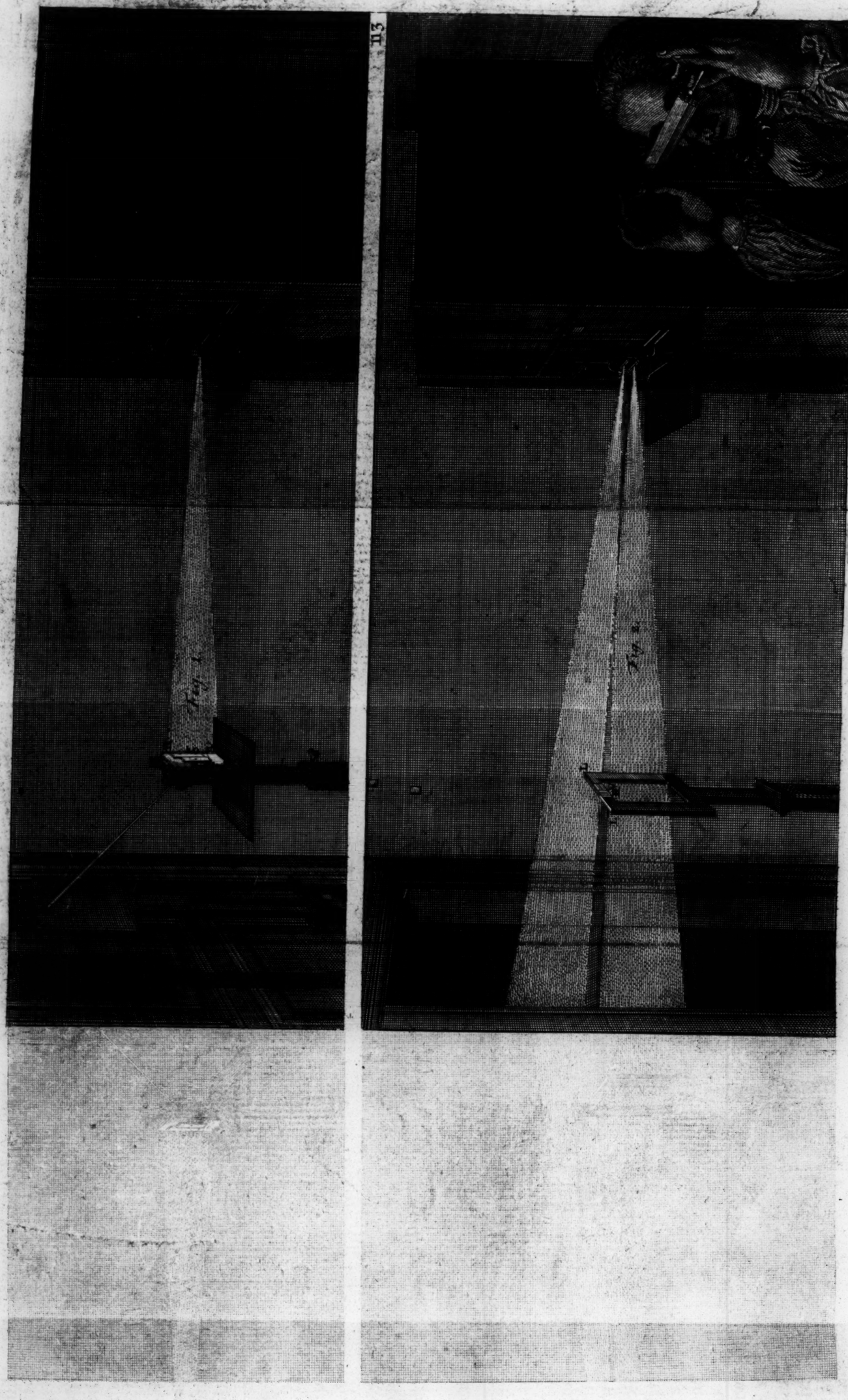
* 3257. required, that they may be all reflected *.

PRISMS, *with their Stands, whereby Experiments concerning Reflection are demonſtrated.*

3552. Plate 114. Fig. 3. In theſe Priſms A B, C D, that are equal and ſimilar, are made uſe of, the Baſes of them are rectangular Iſoſceles Triangles, ſo that when joined, the greater Surfaces being apply'd, they make a Parallelopiped, whoſe Baſes are Squares; the Baſes of theſe Triangles thus joined are put into the Boxes E E, and the Priſms are faſtened by Means of the Screws *f*, *f*, *f*, *f*, which preſs the Plates *g*, *g*: Theſe are apply'd to the Glaſs immediately, and are bent in ſuch Manner that the Screws may not damage the Glaſs, though they paſs through the Plates, whilſt they are joined to them.

3553. Plate 114. Fig. 4. The Priſms thus joined together, may be turned about their common Axis, by Means of the Points cohering with the Boxes: To this End we put the Priſms upon the wooden Stand S, and the Priſms are kept in the required Poſition by Means of the Screw *g*.

3554. Sometimes only one Priſm is made uſe of, then the Places, which occupy the Extremities of the other in Boxes, are filled with wooden Triangles, as H (*Fig.* 3.) and the one Priſm is faſtened in the ſame Manner, as has been ſaid of the two, and is laid upon the Stand. We



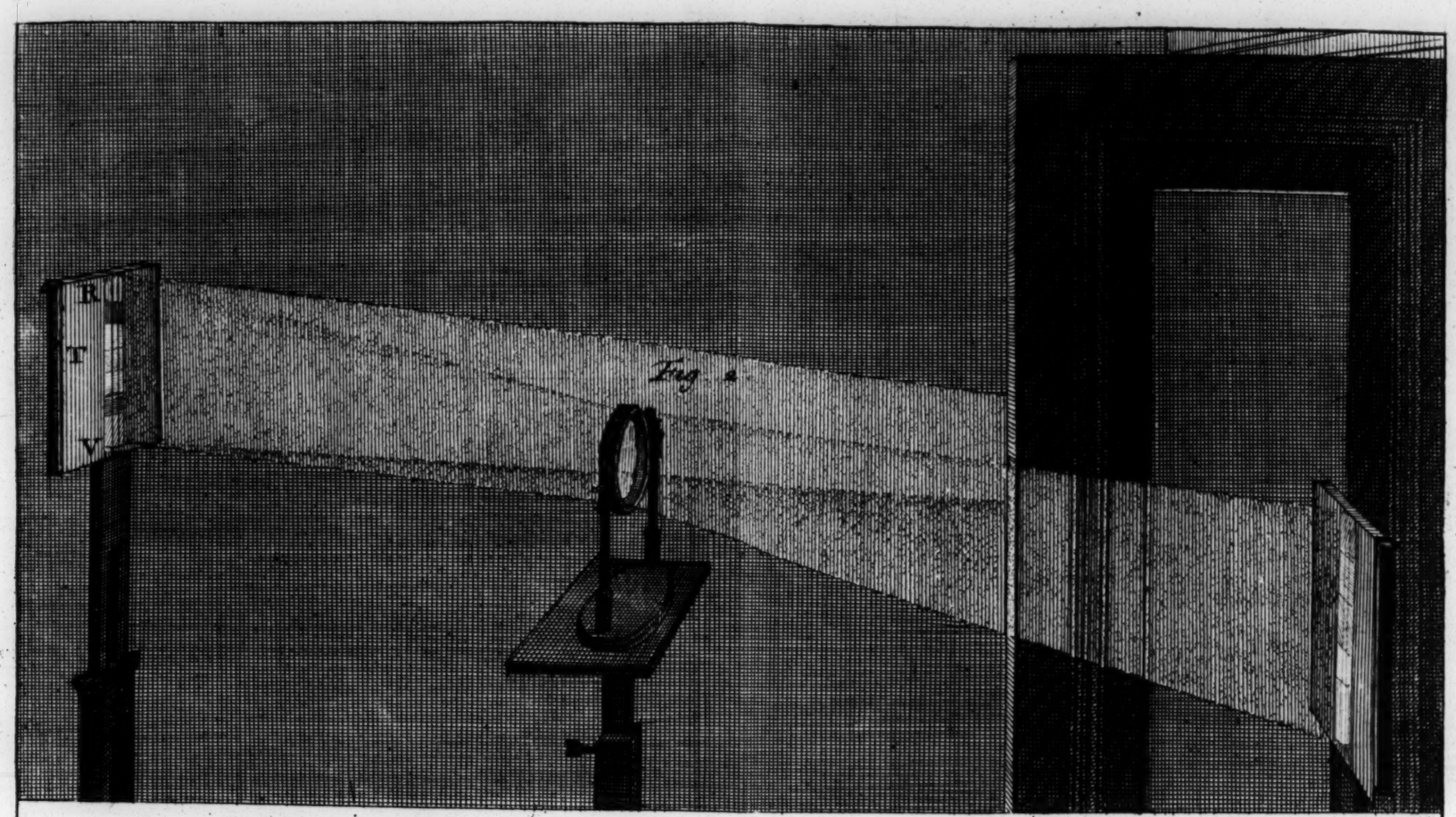
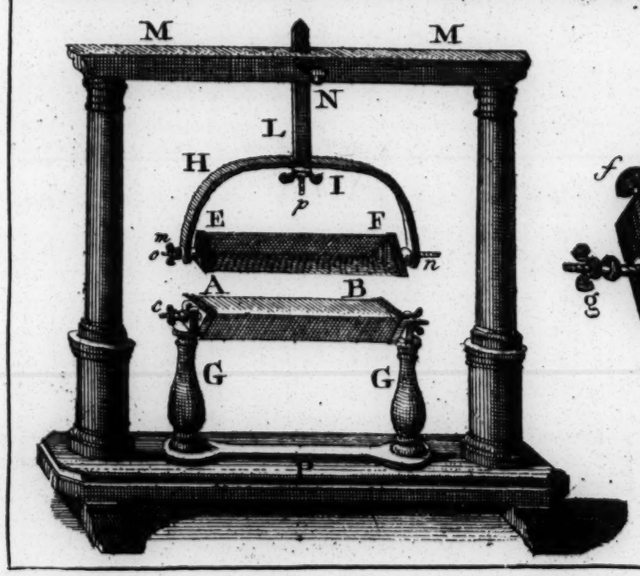


Fig. 2.



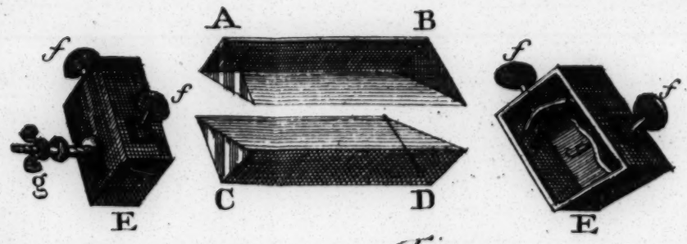
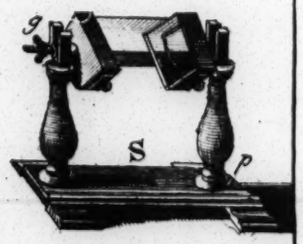


Fig. 3.





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We repreſent the Priſms in an horizontal Poſition, we may alſo make uſe of them in a vertical Poſition, for the Length of the Point muſt be determined in ſuch Manner, that the Side *o p*, and the End of the Point, may be in the ſame Plane perpendicular to the Axis of the Priſm. 3555.

Experiment 4.

A Ray of the Sun is let into a dark Chamber, through a Hole, whoſe Diameter is equal to a Quarter of an Inch. 3556.

If the Direction of it be not convenient enough, it muſt be reflected by a Mirror, and indeed brought into an horizontal Direction; this at leaſt is moſt convenient, and then the Priſm is to be put into a vertical Poſition. Plate 117, Fig. 1.

Only one Priſm A B is made uſe of, into which the Rays penetrate, through one of the ſmaller Sides of it, in ſuch Manner, that it is partly reflected by the greater Sides, and Part of it goes out.

This laſt Light falling upon the white Paper *t*, gives a colour'd Image, the Priſm is turned in ſuch Manner, that the Rays may paſs through near the Surface of the Priſm; the reflected Light is refracted by the Priſm P, and gives a colour'd Image R V at T.

Now if you continue to turn the Priſm ſlowly, in ſuch Manner, that the Obliquity of the Rays falling upon the lower Side be increaſed, the violet Rays will not be able to penetrate into the Air, but they will all be reflected: If you continue the Motion all the purple Rays are reflected, afterwards the Blue, and the eſt according to their Order in the Image *r*, *v*, which continually aſcends, whilſt the upper Part vaniſheth, the red Part, which conſiſts of the leaſt refrangible Rays, vaniſhes laſt. 3557.

In the mean Time the Colours of the Images R V are altered, and that becomes more intenſe ſucceſſively, which vaniſhes in the other Image. 3558.

CHAP. XXIII.

Of the Mixture of Colours, and Whiteneſs.

WE have already ſaid that the Refrangibility and Colour of Rays is not changed by the Mixture of Rays of different Refrangibility *, which is manifeſt by Experiments. 3559.

* 3413.

Ex-

Experiment 1.

3560. This Experiment is made in the ſame Manner as the ſecond of
* 3541. the foregoing Chapter, but by turning the Axis of the upper Priſm*, the Spots are confuſed, and make one purple Spot; but the Colours appear ſeparate to a Spectator, who beholds it through a Priſm, and neither the Colour nor Refrangibility are altered by this Confuſion of Colours.

Experiment 2.

3561. If the oblong coloured Image of the Sun, which was ſpoken
Plate 115. of in the firſt Experiment of the twenty firſt Chapter, falls upon the
Fig. 1. convex Lenſe L * at RV, placed at the Diſtance of ſix Feet from
* 3547. the Priſm BB; the diverging Rays converge by the Refraction of the Lenſe, and mutually interſect one another at A, at the Diſtance of ſix Feet; if the Frame T be at a greater Diſtance, the Rays, which diverge again after their Interſection, come to it diſperſed, and there is again given an oblong colour'd Image; but the Colours, by Reaſon of their Interſection at A, are diſpoſed in a contrary Order, but they are not altered by the Mixture at A.

Experiment 3.

3562. All Things remaining as in the foregoing Experiment; if ſome
Plate 115. Rays of the Image RV be intercepted by the black Paper, which
Fig. 1. alters the Mixture, which by this Method may be varied at Pleaſure, the Colours of the reſt of the Rays, which are again ſepa-
3563. rated, are not altered. *If the Sun Rays*, as they come to us, *be wholly reflected by any Body, this appears white*; but theſe Rays are
* 3465.3495. an Aſſemblage of Rays of different Colours †; whence we infer
3564. that *a Mixture of different Colours conſtitutes Whiteneſs*, for if the Colours which are obſerved in the oblong Image of the Sun, ſo often mentioned, be mixed and confuſed, in the ſame Proportion as they are in that Image, Whiteneſs is produced; which alſo proves, that in that Reſpect the Rays are unchangeable. The Rays that come from the Sun appear white, but if they are ſeparated, their Colours are diſcovered; and, if they be mixed again, the Whiteneſs will be reſtored.

Experiment 4.

3565. Things being diſpoſed as in the two foregoing Experiments,
Plate 115. let the Board T be placed at A, in the very Place where all the
Fig. 2. Rays

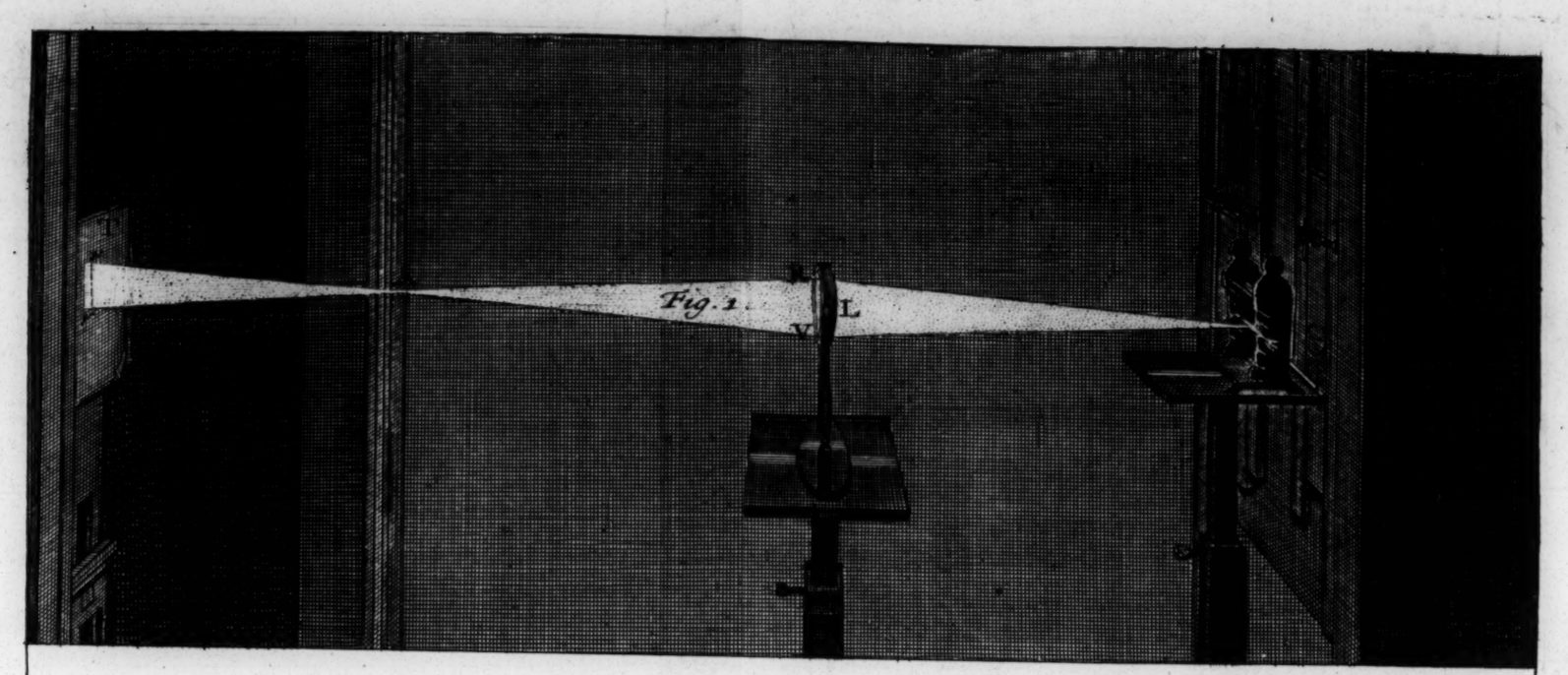


Fig. 1.

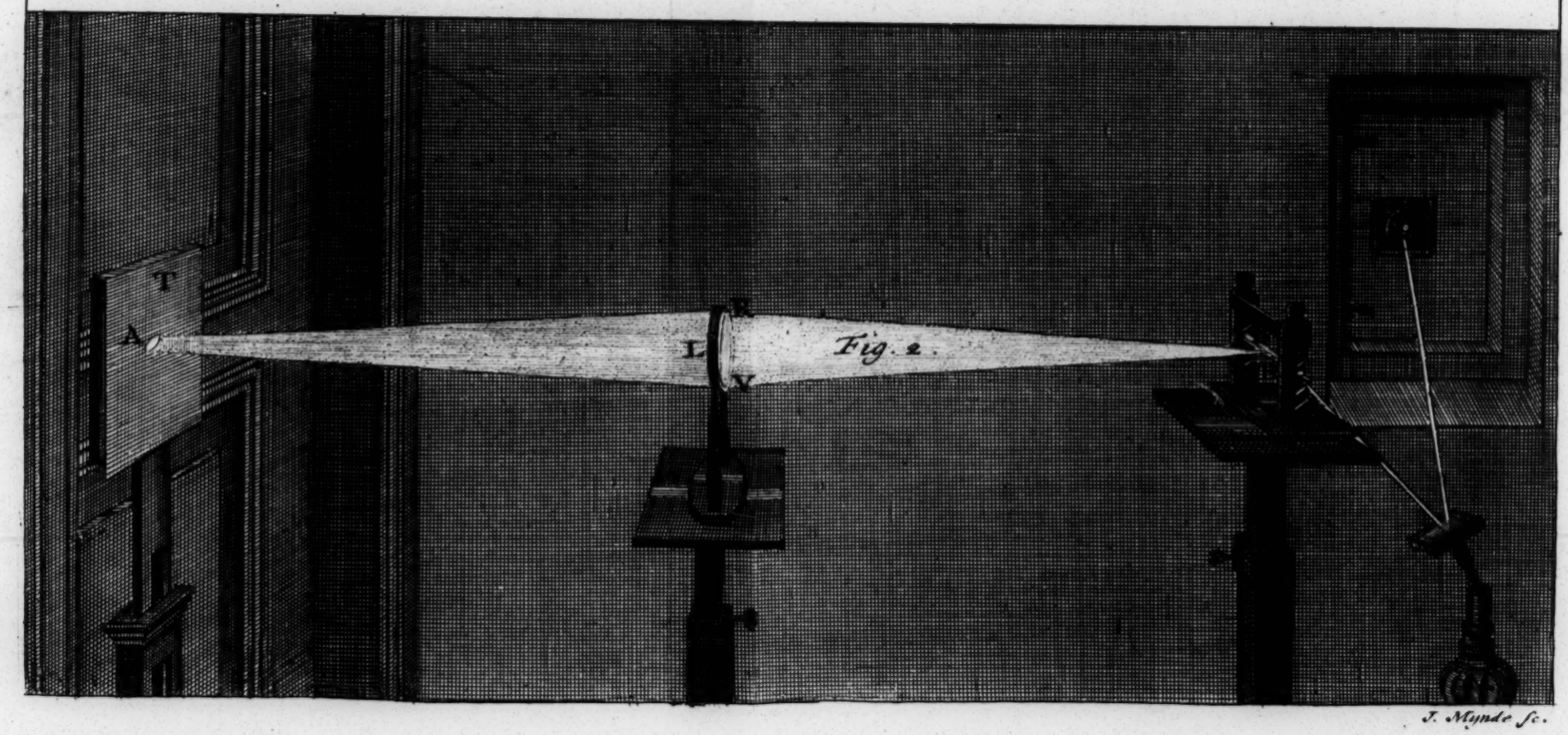


Fig. 2.

J. Mynde Sc.

Rays of the Image R V are mixed together; there will be a Whiteneſs at A, if with a black Paper you intercept the red Colour of the Image R V, the white will vaniſh, and the Colour at A be bluiſh; but if you intercept the violet and blue Rays, the white becomes reddiſh.

If we would have the white Spot greater, we make uſe of that Lenſe which has been mentioned in the fifth Experiment of the twentieth Chapter, but we place this in the Middle between the Priſm and the Board T, which is at the Diſtance of ſixteen Feet from it. 3566.

EXPERIMENT 5.

Take three triangular Priſms made of glaſs Plates *, B B, C C, D D, containing Water; the Sun Rays are refracted through the Priſm B B, as in the third Experiment of the twentieth Chapter, and the oblong Image of the Sun falls upon the Face of the Priſm C C, placed in a Situation parallel to the Face of the Priſm B B, at the Diſtance of three or four Feet, out of which the Rays go. In the ſecond Priſm the Rays undergo Refraction, contrary to that which they did in the firſt, by Reaſon of the Paralleliſm mentioned, and becauſe the Angle which the glaſs Planes make, through which the Rays paſs, are equal: Therefore the firſt Refraction is deſtroy'd by the ſecond, and the Rays go out of the Priſm C C at R V parallel, for the Priſms are ſo placed, that if the Priſm C C be brought near the other, and the parallel Faces mutually touch one another, the Light may paſs through the Medium, terminated by parallel Planes; for both the Priſms joined together make a Parallelopiped, through which Light, of any Refrangibility paſſes without Change of Direction ** now the Priſms are ſeparated, that the heterogeneous Rays may be ſeparated, before they again become parallel, if theſe coloured Rays fall upon the third Priſm D D, and in paſſing through it undergo a Refraction like that which they have undergone in paſſing through the firſt or ſecond Priſm; the Rays that go out at *r v* converge, on Account of unequal Refractions in Rays of different Colours, and concur at A, in which Place alſo Whiteneſs will be produced, as in the foregoing Experiment. 3567. Plate 116. Fig. 1. * 3491. 2792.

EXPERIMENT 6.

Let R V be an oblong coloured Image of the Sun, as in the firſt Experiment of the twentieth Chapter, and let there be a Spectator at S at a Diſtance from the Plane T, as much as the Priſm is diſtant from it, by which the Rays are ſeparated; if he looks at the 3568. Plate 116. Fig. 1.

Image V R through another Priſm like the firſt, as was ſaid of the Hole in the fourth Experiment of the ſame Chapter, he will ſee the Image round and white; the ſecond Refraction deſtroying the firſt in ſuch Manner, that the Rays enter the Eye being again mix'd.

Experiment 7.

3569. Plate 118. Fig. 1. All Things being ordered as in the fourth Experiment foregoing, the Priſm is placed at A in the Point in which the Rays being mixed are white; the Rays are refracted downwards, and indeed in ſuch Manner, that the Deflection is the ſmalleſt; which Poſition of the Priſm is found, by turning it about its Axis, then (for we ſuppoſe the Priſm P and A to be ſimilar) the ſecond Refraction deſtroys the firſt, and the Rays go out of the ſecond Priſm along *e*, *f*, as they enter into the firſt along *c*, *d*, parallel and white; now if this white Ray *ef* be refracted through the third Priſm B horizontally, we have a new oblong Image *v r*, tinged with the Colours often mentioned.

Experiment 8.

3570. Plate 117. Fig. 2. * 3552. In this Experiment all Things are diſpoſed, as in the laſt Experiment of the foregoing Chapter; but a ſecond Priſm C D* is joined with the Priſm A B, a ſmall Piece of Paper being put between, at the Extremities of the Priſms.

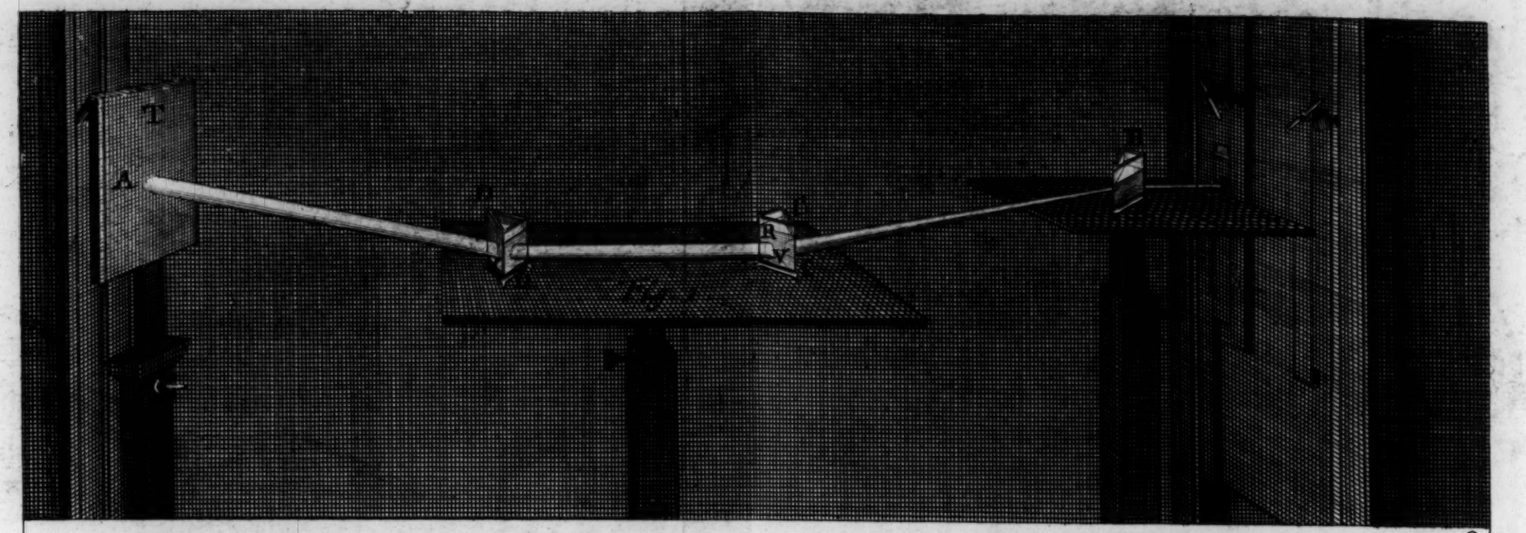
Then the Rays, which paſs through the two Priſms, make a white Spot *m*, ſuch as the Rays reflected at M give.

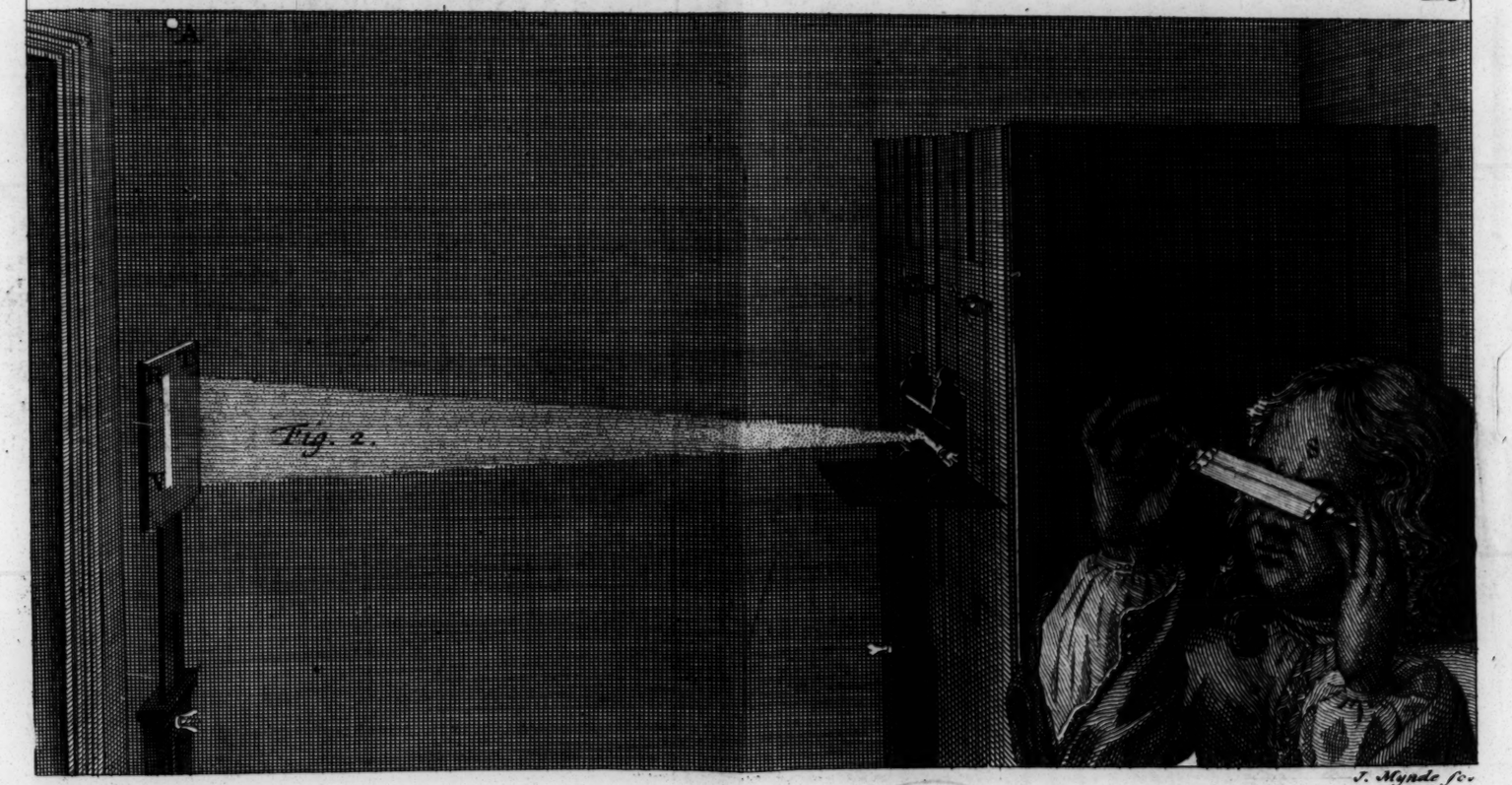
Now the Priſms being turn'd about their common Axis, in ſuch Manner that the Rays of all the Colours may be ſucceſſively reflected, the Whiteneſs of both the Spots M and *m* is alter'd, by Reaſon of the Alteration of the Mixture of the Rays.

3571. If the Planes T, *t*, being removed, the Priſms be placed at M *m*, by which the Colours are ſeparated, we ſhall have the ſame * 3557.3558. Phenomena in the colour'd Images, that were mention'd before*.

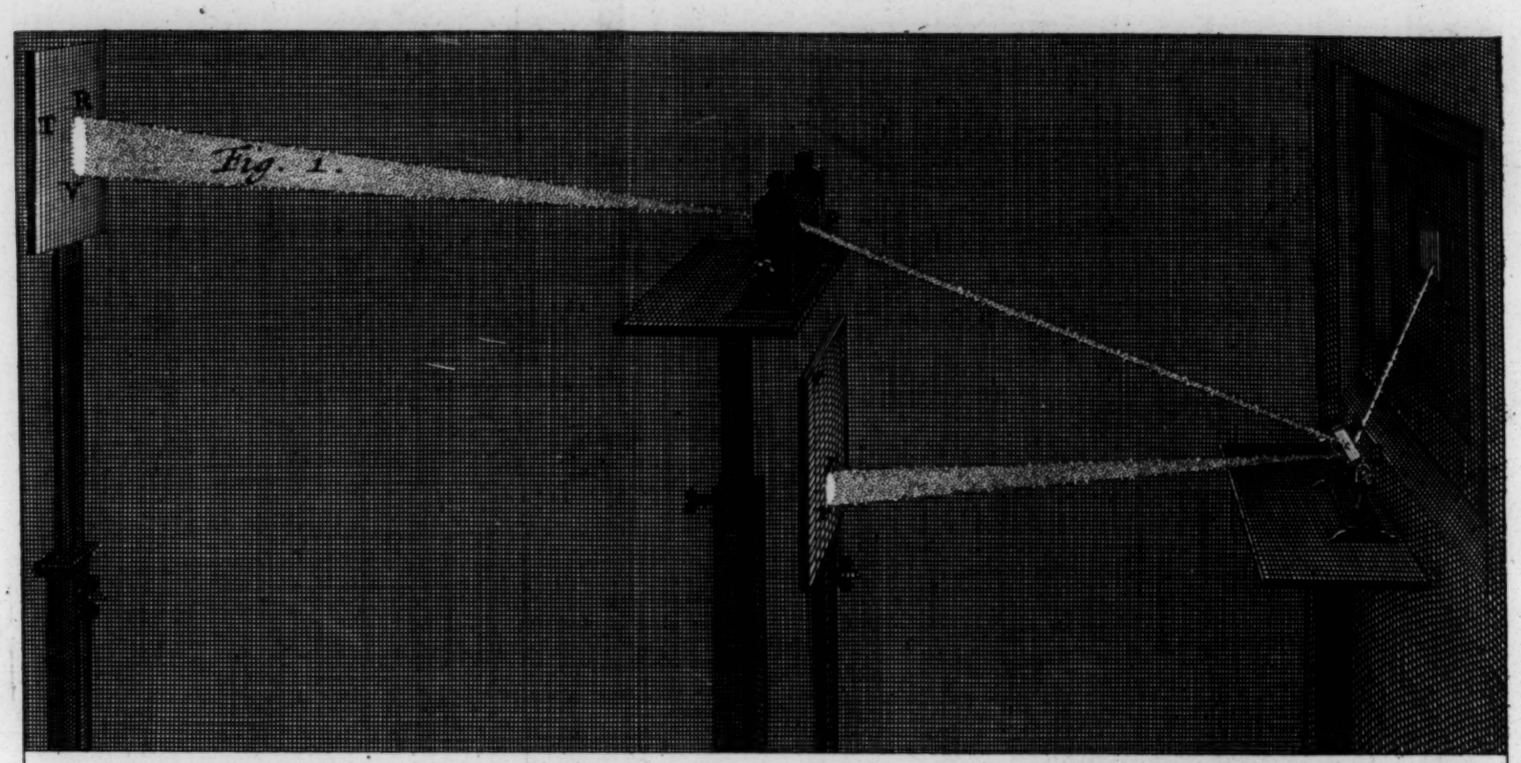
3572. *A Mixture of all the Colours, which are obſerved in the oblong Image of the Sun, is not neceſſary to conſtitute Whiteneſs*; the Whiteneſs of the Sun's Rays is a little inclined to yellow; and the yellow Rays being partly taken out of the Mixture, the white becomes more perfect. Whiteneſs is produced from the Mixture of four or five Colours, the juſt Proportion being kept; *the primary Colours*, that is the homogeneous Colours, being mix'd, *generate many Colours different from the homogeneous, or primary Colours*; oftentimes

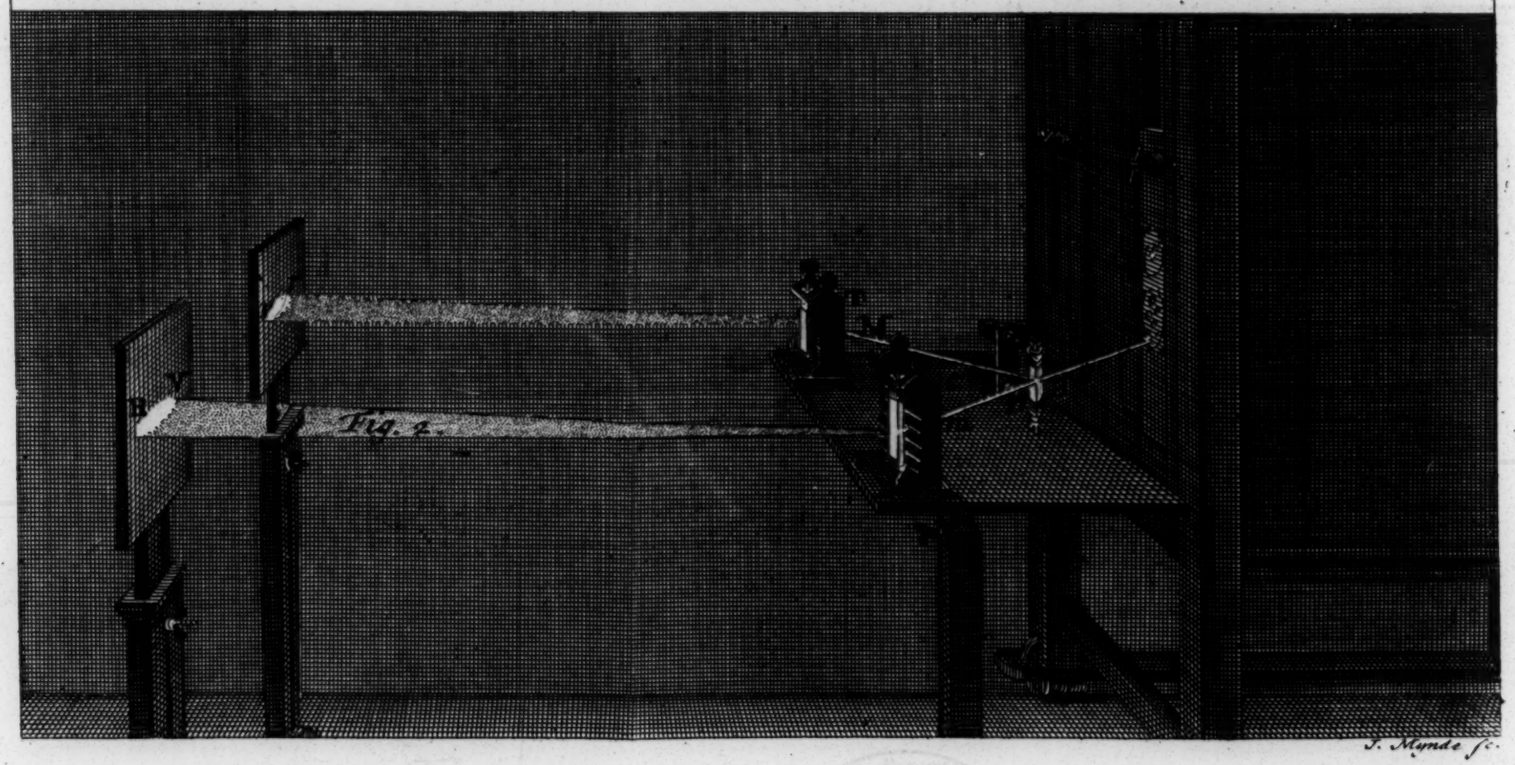
3573. a Colour,





J. Mynde sc.





J. Mynde sc.

a Colour, like an homogeneous Colour, is made up of the Mixture of other Colours, and theſe three Colours, red, yellow, blue, being given, we may imitate all the Reſt; but we ought not from thence to infer, that there are only three primary Colours, ſince we really diſcover ſeven: Nevertheleſs *when no Difference is obſerved between the homogeneous Colour, and that which is mixed by the naked Eyes, this is ſenſible through the Priſm.* 3574.

EXPERIMENT 9.

Let any ſmall Objects, as Letters on Paper, Flies, and other ſuch like Objects, be obſerved through a Priſm, if they be expoſed to the mix'd Light they appear to be confuſed; if they be enlightened with homogeneous Light *, when ſeen through the Priſm, they are terminated by diſtinct Limits. 3575. * 3510.

CHAP. XXIV.

Of the Rainbow.

HAVING finiſhed what relates to the Rays enlightening Bodies, we muſt not leave this Subject, without explaining a Phenomenon, which is too remarkable and common to be paſſed by in Silence. 3476.

The Rainbow, or Iris, is what every Body has often ſeen: Having firſt premiſed ſome Things, we muſt explain what is the Cauſe thereof.

Let there be Water encompaſſed with Air, terminated by the Circle BDFH, *let homogeneous Rays, which are parallel, fall upon it*, whereof AB is one; let the Semi-diameter CB be drawn and continued to N, this is perpendicular to the Surface ſeparating the Mediums, therefore ABN is the Angle of Incidence; this Angle is equal to the oppoſite vertical Angle CBL*, whoſe Sine is CL perpendicular to BL, and going through the Center, the Ray is refracted towards the perpendicular *, and CBM is the Angle of Refraction, whoſe Sine is CM drawn from C perpendicular to BD; for every Ray, ſuch as AB, the Ratio between the Lines, ſuch as CL and CM is the ſame *. 3577. Plate 118. Fig. 2. * 2918. * 15.El.1. * 2798. * 2809.

The Ray BD in Part penetrates into the Air in the Direction E, and in Part is reflected in the Direction DF, ſo that the Angle of Reflection CDF, is equal to the Angle of Incidence BDC*; * 3241.

conſequently B D and D F are equal; alſo the Ray D F does in Part go out of the Water along F G, and is reflected along F H; which in the ſame Manner does in Part go through H I, and in Part is reflected; but we do not conſider this Reflection, and other farther Reflections and Refractions; they are too weak, becauſe of the ſeveral Diviſions the Light has undergone.

Experiment 1.

3578. Plate 119. Fig. 1. ‖ 2794. 2795. 2769. We let an horizontal Ray into a dark Place *, and intercept it by the Board, whoſe Inciſion is horizontal ‖, and which we repreſent by the Line A B. In the Inciſion we leave a ſmall Aperture, in ſuch Manner, that only a ſmall Ray may paſs through; the Cylinder V made up of pure Glaſs that is thin contains Water, into which the Ray A B C paſſes obliquely, and is refracted along C D; it is reflected along D E, and goes out along D F; it is further reflected along E G, and ſo on: We ſeek the Poſition of the Glaſs by Trial and the Breadth of the Ray, that the Experiment may be very ſenſible, in which Caſe the Reflections are ſo repeated, that they extend themſelves beyond I; but the ſixth Ray is ſcarce viſible, and often cannot be perceived.

Plate 118. Fig. 2. The Ray F G, which after one Reflection goes out of the Water, makes the Angle G P A with the incident Ray A B, which varies in different incident Rays; therefore, though theſe Rays

Plate 118. Fig. 3. ſhould be parallel, *they will be diſperſed when they go out after one Reflection*, as is evident by looking at the Figure.

3579. The Ray E E, which being continued, paſſes through the Center C, is not turned out of it's Way, either by Reflection or Re-

* 3272. 2793. fraction.

As you recede from this Ray, the Ray which returns is leſs and leſs inclined continually to the incident Ray. Thus the Ray D D, which goes out of the Water along *d d*, and returns along that Line, makes a greater Angle with D D, than the intermediate Rays D D and E E do make with their returning Rays, which go out of the denſer Medium.

3580. Let B B be a Ray, in Reſpect of which this Inclination is the leaſt of all, that is, which makes an Angle as A P G (*Fig.* 2.) the greateſt of all: Beyond B B, the returning Rays are more inclined towards the incident Rays; thus A A returns along *aa*:

3581. From this Diſperſion *of the returning Rays*, receding from the Place where the Rays are bent, they become continually weaker and weaker; and their *Colour cannot be perceived throughout the*

whole Space which they fill, though *the Colour* of the incident Rays be vivid; the Colour in the returning Rays *is only ſenſible where the adjacent Rays are parallel, and* thoſe next to them diverge but a little, ſo that at a great Diſtance they are denſe enough to be perceived: *Theſe only are ſaid to be efficacious*, and will be ſo, where the incident Rays being refracted, meet in the very Point of Refraction.

Let A B, *a b* be adjacent Rays, parallel to one another, and falling upon a circularSurface terminating the Water; if theſe, being refracted along B D, *b* D meet in D the Point of Reflection, the reflected Rays D F, F *f*, will make with F *f* Angles equal to thoſe which D B, D *b* make with B *b*; and ſo the refracted Rays, F G, *f g*, will be parallel * and efficacious †. In the firſt Scholium following we have demonſtrated how, in this Caſe, when the Ratio between the Sines of Incidence and Refraction is given, the Angle formed by the incident Ray and the returning efficacious one, may be determined, that is, the Angle A P G, which here is the greateſt of all. 3582. Plate 118. Fig. 4. * 3790. † 3581.

When the Ratio between the Sines of the Angles of Incidence and Refraction varies, the Angle A P G is changed; which therefore is different, according to the different Refrangibility of the Rays. 3583.

If the Surface abovementioned be enlightened by heterogeneous Rays, as they flow from the Sun, *the efficacious Rays of different Colours do not make equal Angles with the incident Rays, and ſo the Colours are ſeparated by Help of this Refraction.* 3584.

Experiment 2.

This Experiment is made in the ſame Manner as the foregoing one, but we make uſe of another Board T *, becauſe it is not neceſſary, that the Ray be ſo ſtraitened; and the Height of the Ray, going into the Water, may now be determined at Pleaſure. The Poſition of the Glaſs is alſo eaſily diſcovered by making Trial, that the efficacious Rays of all Colours may return; the Rays that paſs through the Slit of the ſaid Board are ſufficient that we may have all the Colours. 3585. Plate 119. Fig. 2. * 2768.

If theſe efficacious Rays fall upon the white Paper, at the Diſtance of four or five Feet, the Colours will appear ſeparated according to their Order of Refrangibility *, and by Reaſon of the Figure of the Glaſs the Colours will appear vertical. * 3501.

If

3586. If the Paper being removed the efficacious Rays enter into the Eye of a Spectator S, placed at a greater Diſtance, that the Colours may be more ſeparated, the Spectator will ſee that Colour, the Rays of which enter into the Eye; and he will perceive all the Colours ſucceſſively, by moving his Eye.

3587. But with Regard to thoſe Rays, which after a double Reflection in Water emerge, they will be efficacious, if they be parallel after the firſt Reflection; for then F H, *f h*, are in the ſame Manner inclined to H *h*, as B D, *b d* to B *b*; and therefore, ſuppoſing the incident Rays A B, *a b* to be parallel, the emerging Rays H I, *h i* will be parallel too, that is, efficacious*.

Plate 119. Fig. 3.

* 3249.

3588. Alſo in the ſecond Scholium following, we demonſtrate, how in that Caſe the Angle H P B, formed by the emerging and incident Ray is determined, which Angle in that Caſe is the ſmalleſt of all ſimilar ones, being different according to the different Refrangibility of the Rays: Whence alſo in that Caſe, *the efficacious Rays of different Colours, ſuppoſing the incident Rays parallel, are ſeparated after a double Reflection.*

3589.

Experiment 3.

3590. All Things being ordered as in the laſt Experiment, the Situation of the Glaſs that contains the Water is altered, ſo that the Rays which are efficacious after two Reflections in the Glaſs fall upon the Paper, or, when this is remov'd, upon the Eye.

Pl. 119. Fig. 2.

3591. What has been hitherto explained, may be applied to the *Rainbow*; in order to produce which Phenomenon, *it is required that Drops of Water be ſuſpended in the Air; that the Spectator be placed with his Back towards the Sun, between it and the Drops, and that there be a dark Cloud behind the Drops*, that the Colours may be more ſenſible, for theſe are ſcarcely perceived, if vivid Light enters the Eye at the ſame Time.

3592. Theſe Things being ſuppoſed, if we conceive all the Drops to be cut by Planes, paſſing through the Centers of the Drops, and the Sun, and the Eye of the Spectator: What has been demonſtrated * above, may be applied to each of theſe Sections.

* 3581. 3582. 3583. 3584. 3587. 3588. 3589.

3593. Here we ſpeak of Rays which go out of Air into Water. In red Rays, that is, ſuch as are the leaſt refrangible, the Ratio between the Sine of the Angle of Incidence and the Angle of Refraction, is as 108 to 81, or, which is the ſame, as 4 to 3; with which Numbers, if the Computation be made, the Angle A P G will be 42 Degrees 2′, but if we ſpeak of violet Rays, the Ratio

Plate 118. Fig. 4.

the Sines is as 109 to 81; which Numbers give the ſame Angle A P G of 40 Deg. 17 Min.

If the Computation be made for the Angle A P I, and the Rays be red, the Angle will be 50 Deg. and 57 Min. if the Rays be violet, the ſame Angle is 54 Deg. 7 Min. as will be ſeen in the Scholiums. 3594. Pl. 119. Fig. 3.

Now let the Drops be ſuppoſed to be diſperſed through the Air, and enlightened by the Sun's Rays, which are parallel to one another, and to the Line O F, paſſing through the Eye of the Spectator; let us conceive the Lines *e* O, E C, B O, *b* O, and let the Angles *e* O F be 40 Deg. 17 Min. E O F 42 Deg. 2 Min. B O F 50 Deg. 57 Min. *b* O F 54 Deg. 7 Min. the ſame Lines form Angles with the incident Rays *d e*, D E, A B, *a b*, reſpectively equal to the Angles aforementioned; therefore, if the Drops be conceived at *e*, E, B, *b*, the efficacious violet Rays will enter the Eye, after one Reflection in the Drop *e*; and the red efficacious Rays come to the Eye from the Drop E; alſo after one Reflection the other intermediate Colours are obſerved between *e* and E, in the Order beforementioned *. After two Reflections in the Drop, the efficacious red Rays come to the Eye from the Drop B, and the violet efficacious ones from the Drop *b*; between theſe Drops the intermediate Colours appear in the ſame Manner as between E and *e*, but they are diſpoſed in a contrary Order, and, by Reaſon of their double Reflection, are alſo weaker. 3595. Pl. 120. Fig. 1. * 3501. 3596.

Let us conceive a Line, as O *e*, to revolve about a fixed Line O F, keeping the Angle *e* O F, and to form a Cone or Part of a conical Surface; in every Situation the Line *e* O makes an Angle of 42 Deg. 17 Min. with the Sun's Rays, which are parallel to one another, and to the Line O F; *if* therefore *the Drops be diffuſed* near Part of the Surface of this Cone, at the ſame or different Diſtances *the Eye will ſee the* violet *Bow:* The ſame may be ſaid of the other Colours; therefore, when the Drops are ſuſpended in the Air, a Spectator ſees a Bow, having the Breadth *e* E *tinged with homogeneous Colours* aforementioned *, that are diſpoſed in the ſame Order, as in the Experiments with the Priſms; becauſe the heterogeneous Rays are ſeparated as much in the Drops as in the Priſm*. 3597. 3598. * 3501. * 2472. 3584.

By the ſame Way of Reaſoning it is evident *there will be a broader Bow encompaſſing the firſt, in which the ſame Colours will appear in a contrary Order and weaker.* 3599.

E x-

EXPERIMENT 4.

3600. Hanging up a Piece of black Cloth, expoſed to the Sun Rays, let there be between this and the Sun, a Spectator beholding the Cloth, and let Water be diſperſed between the Cloth and the Spectator, that it may be reſolved into ſmall Drops, the Spectator will ſee the Rainbow, at leaſt the inner one.

SCHOLIUM I.

Computations concerning the firſt Rainbow.

3601. Plate 118. Fig. 1. SUPPOSING what was explained in N. 3582, we muſt demonſtrate, how the Angle A P G is determined, which the incident Rays make with the efficacious returning Rays, the Ratio between the Sines of Incidence and Refraction being given. Let this Ratio be the ſame as is given between I and R; therefore, drawing C *m* perpendicular to *b* D, and the Arch *m n* with the Center C, and Semi-diameter C *m*.

3602. I, R :: C L, C M . : C *l*, C *m* :: C L—C *l*=L *l*, C M—C *m*=M *n*.

3603. Draw B *o* perpendicular to B L; as alſo B *p* to B M; and let *b p* be given, which makes a right Angle with B *p*; laſtly, let the Points B, C, and M, *m* be joined by Lines.

The Triangles B *b o*, B C L, are equiangular, for they are right-angled, and the Angles *o* B *b* and C B L, the Difference of each of which from a right Angle is *o* B C, are equal.

In the ſame Manner may be proved that the Triangles B M C and B *b p* are equiangular, and therefore ſimilar *; the Triangle M *m n* right-angled at *n*, is alſo ſimilar to this; for the Sides M *n*, B *p*, perpendicular to the Line B D, are parallel; as alſo M *m* and B *b*, becauſe the Lines B D, *b* D, are biſected into equal Parts at M and *m* *; therefore alſo B *b* is double of M *m*, and B *p* double of M *n*. Hence we deduce,

* 4 El. 6.

B L, B C : : B *o*, B *b*.
B C, B M : : B *b*, B *p*.

therefore by Equality

3604. B L, B M : : B *o*=L *l*, B *p*=2M *n* : : I, 2 R : : C L, 2C M,

* 3602. by comparing theſe Proportions with that beforementioned *.

3605. As the Squares of proportional Quantities are proportional *, we have by Alternation,

* 22 El. 6.

B L^q, C L^q : : B M^q, 4C M^q.

when we deduce by Converſion and Inverſion,

* 45 El. 1. B L^q+C L=B C^q *, B L^q : : B M^q+4C M^q=B C^q+3C M^q, B M$_q$=B C$_q$ —C M^q=B L^q+L C^q—C M^q.

By ſubſtracting the firſt and ſecond Term from the third and fourth, whereby the Proportion is not altered, we have

B C

$BC^q, BL^q :: 3CM^q, LC^q - CM^q :: 3R^q, I^q - R^q$; 3606.

for there is the ſame Ratio between CM and LC as between R and I*. * 3602.

But as the Ratio between R and I is given, the Ratio between the Semidiameter BC, and the Line BL is known, which is the Sine of the Angle BCL, which Angle therefore is given; therefore the Arch BN is known, as alſo FH, for theſe are equal.

As to red Rays, I is to R, as 4 to 3. Therefore, 3607.

$$27, 7 :: BC^q \left(\overline{100.000^2}\right) BL^q.$$

And we find BL=50916; which Number is the Sine of the Angle 30°. 37′. Wherefore the Arches BN and FH are each equal to 61°. 14′.

The Sine BL being given, the Sine BM of the Angle BCM is alſo given; becauſe I (4) 12 R (6) :: BL (50916,) BM=76374=the Sine of the Angle 49°. 48′*. therefore the Arch BD is determined, to which DF is equal, and each is 99°. 36′. 3608. * 3604.

TCDP being drawn, the Arch BT is 80°. 24′. and DN is 38°. 22′. the Meaſure of the Angle BDT is half of the Arch BT*, alſo the the Meaſure of the Angle NBD is half of the Arch ND; the Angle TPB is equal to the Difference of the ſaid Angles*, and has for its Meaſure the half of the Difference between the Arches BT and DN, and this whole Difference of 80°. 24′—38°. 22′.=42°. 2′. is the Meaſure of the whole Angle APG, as has been ſaid above*. 3609. * 20. El. 3. * 32. El. 1. * 3593.

When the Ratio between I and R varies, the Angle APG is alter'd; which is different according to the different Refrangibility, as has been ſaid above*. * 3583.

For the violet Rays I is to R, as 109 to 81; and if the Computation be made with theſe Numbers, the Arch BN is found to be 62°. 39′. and BD 101°. 11′. as alſo DN 38°. 32′; laſtly, BT, 78°. 49′. Therefore the Meaſure of the Angle APG, which is equal to the Difference between BT and DN, is 40°. 17′. as has been alſo obſerved above†. 3610. † 3593.

SCHOLIUM II.

Computations concerning the ſecond Rainbow.

WE have ſeen that the Rays are efficacious, that return after two Reflections in the Drop, if after the firſt they be parallel, as DF, *df**; in this Caſe *d*D is the half of the Difference between the Arches DF and *df*, or DB and *db*; but their Difference is B*b* minus D*d*; if therefore this be ſubſtracted from that, there will remain the double of the Arch D*l*, the triple of which is therefore B*b*. 3611. Plate 119. Fig. 3. * 3587.

The Rectangle made of DE and EB is equal to the Rectangle made of *d*E and E*b**;

Therefore DE, E*d* :: *b*E, EB†,

and B*b* being put ſo ſmall, that it may be taken for a right Line, the Triangles B*b*E, and D*d*E will be ſimilar*. * 35. El. 3. † 16. El. 6. * 6 El. 6.

3612. Therefore D E is to E *b*, or E B : : D *d*, B *b*, that is, as 1 to 3.

Therefore M D is divided into two equal Parts at E; and M E s a third Part of E B, and *m* E a third Part of E *b*.

3613. Now if, as in Fig. 4. Pl. 118. the Triangles B *o b*, B *p b* and M *m n* be formed, M *m* will be a third Part of B *b*, and B *p* triple of M *n*; now if, mutatis mutandis, we apply to this Figure, what has been demonſtrated concerning the ſaid Figure *, we have,

* 3601. * 3602. I, R : : C L, C M : : L *l*, M *n* *.

3614. B L, B M : : L *l*, B *p* = 3 M *n* : : I, 3R : : C L, 3 C M *.

* 3604. Whence by Reaſoning we deduce, as above *,

* 3605. B C^q, B L^q : : 8 R^q, I^q — R^q.

3615. From which Proportion, as was ſaid of Fig. 4. pl. 118*, the Arch

* 3609. B N is diſcovered, to which H G is equal; and becauſe in this Caſe, as has been ſeen,

† 3614. B L, B M : : I, 3R †.

The Arch B D is alſo diſcovered, to which, by reaſon that the Angles

* 3271. of Reflection are equal to the Angles of Incidence *, D F and F H are equal.

3616. From which being given, the Arches N D T, and B *t* are eaſily found,

* 3609. the Difference of which, as follows from what is demonſtrated above *, is the Meaſure of the Angle H P B, made by the Ray going out with the incident Ray; which Angle in this Caſe is the ſmalleſt of all ſimilar ones, and different according to the different Refrangibility of the Rays.

3617. Let, as above, * I be to R, as 4 to 3, and we have 72. 7 : : B C_q, B L_q,

* 3607. whence we find B L to be the Sine of the Arch 18°. 10′ ½, and the Arch B N to be 36°. 21′.

We alſo have, 4, 9 : : B L, B M, and we find this laſt Line to be the Sine of the Arch 44°. 33′. which if it be tripled, there will be given the Arch B D T 133°. 39′. ſubſtracting the Arch B N, there remains N T, 97°. 18′. ſubſtracting B D T from the two right ones, there is given B *t*, 46°. 21′. and the Meaſure of the Angle ſought A P I = G P N is 97°.

* 3594. 18′. — 46°. 21′. = 50°. 57′. as above *.

3618. Theſe Things relate to red Rays; as to the violet ones, I is to R, as 109 to 81. If the Computation be made with theſe Numbers, B N is 37°. 8′. B D T 135°. 37′. N T, 98°. 29′ ½. B *t* 44°. 22′ ½. whence we

* 3594. deduce the Angle ſought A P I 54°. 7′. as has been alſo ſaid above *.

CHAP. XXV.

Of the Colours of thin Plates.

3619. WE proceed to the Colours of natural Bodies; and firſt of all we think it proper to examine their thin Plates. Whoever has obſerved very thin Glaſs, or Bubbles of Water made with Soap,

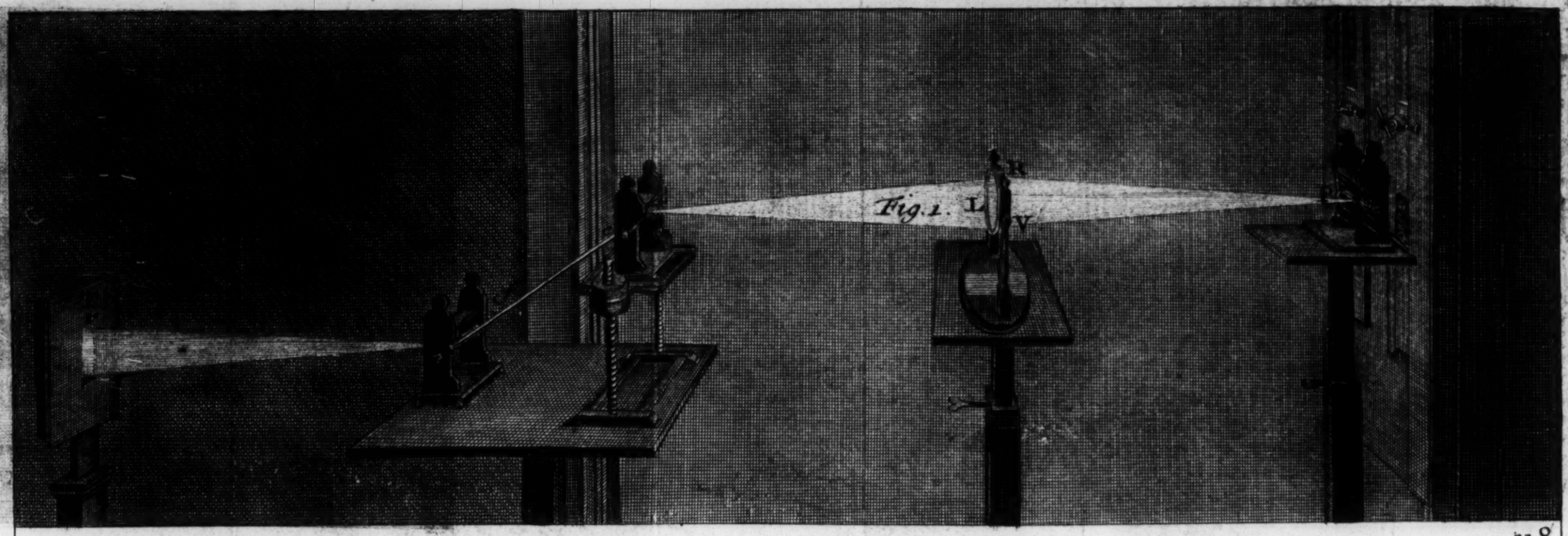


Fig. 1.

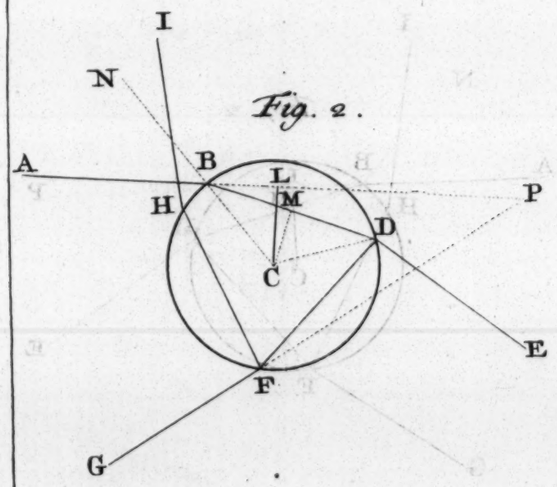


Fig. 2.

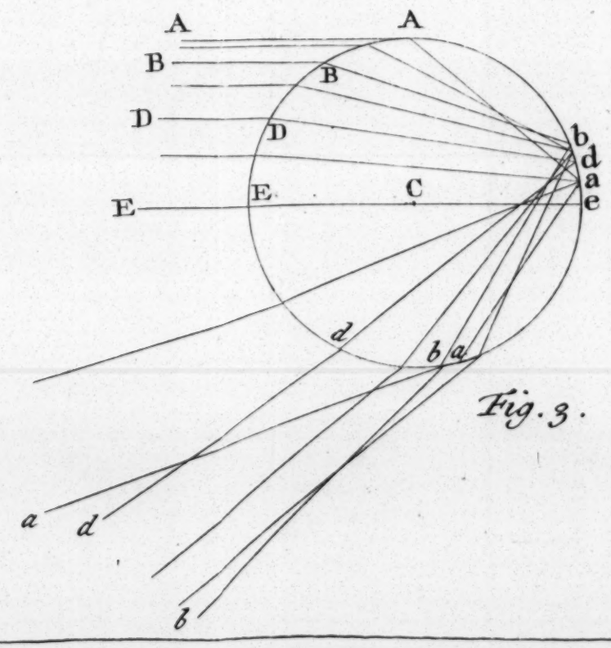


Fig. 3.

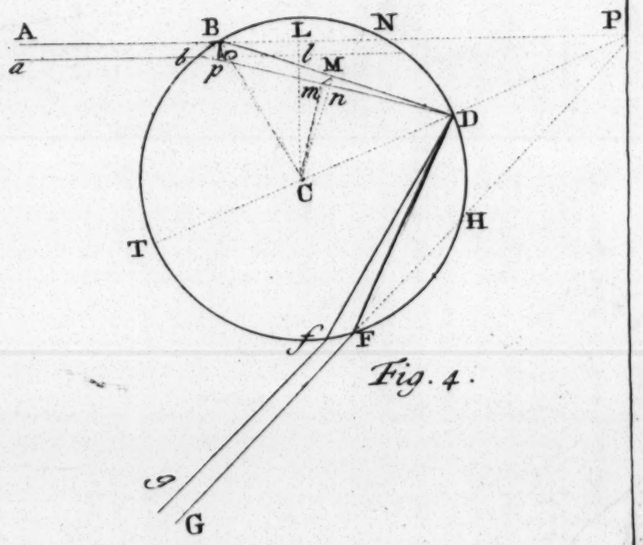


Fig. 4.

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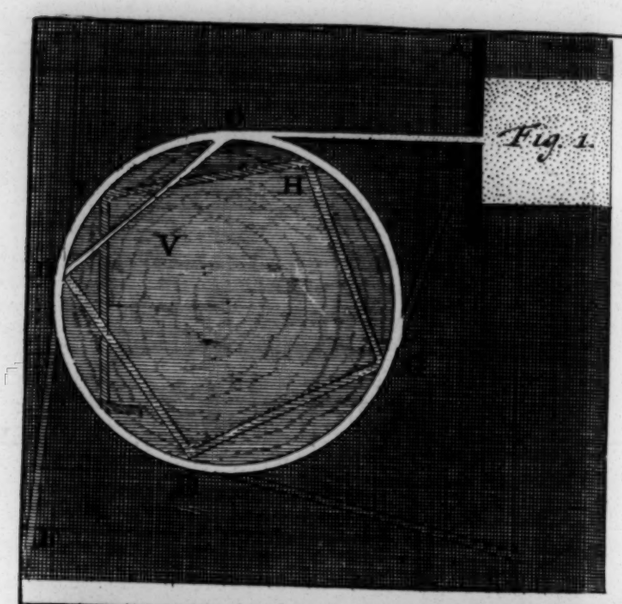


Fig. 1.

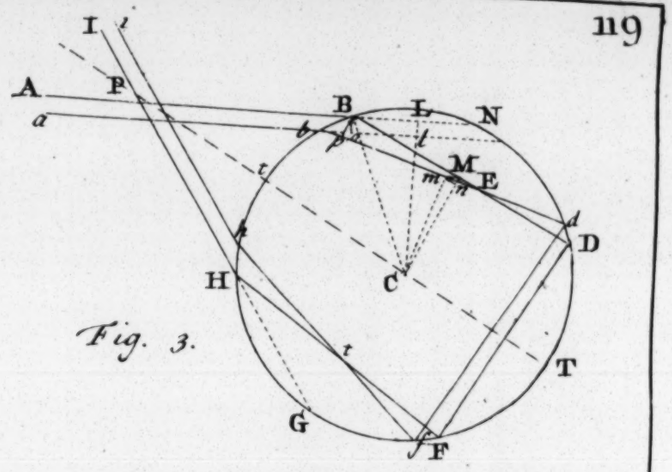


Fig. 3.

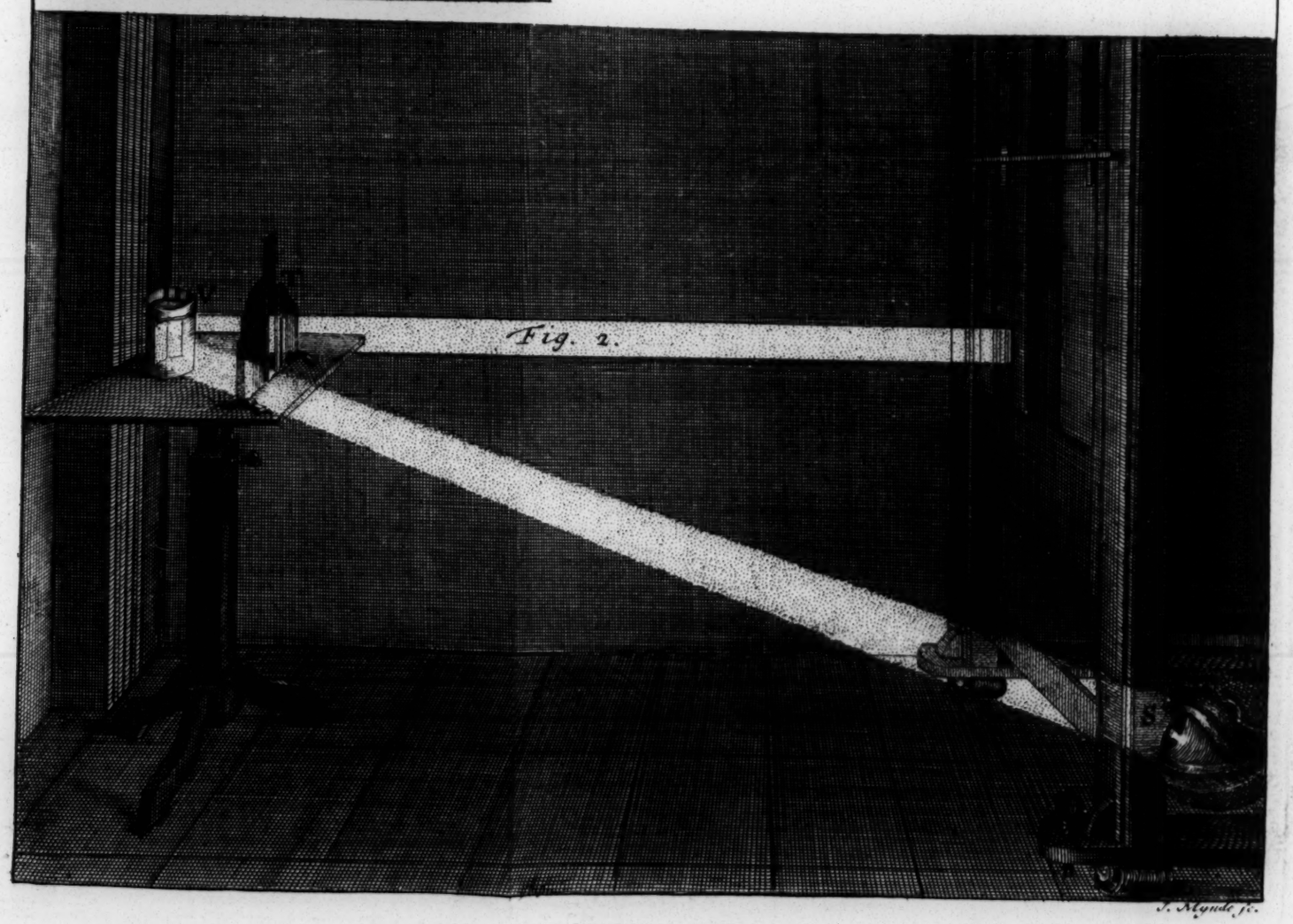


Fig. 2.

J. Mynde fc.

Soap, muſt have eaſily perceived various Colours in them, the reaſon of which is the wonderful Thinneſs of the Plates.

For the Rays of Light, by Means of a thin tranſparent Plate, are ſeparated from one another; and *according to the different Thickneſs of the Plate, the Rays of ſome Colours are tranſmitted, and thoſe of others reflected; and the ſame very thin Plate is of one Colour, when ſeen by the tranſmitted Rays, and another when ſeen by reflected ones.* 3620.

EXPERIMENT 1.

If two object Glaſſes A B and C D, of long Teleſcopes be laid upon one another, and be preſſed hard together, in the Middle, where the Glaſſes touch one another, you will ſee a tranſparent Spot ſurrounded with colour'd Circles. That this may be done regularly and conveniently, we put theſe upon three Feet *p*, *p*, *p*, and preſs together the Glaſſes with Screws, Plates being put between, that the ſaid Spot may be in the Center of the Glaſſes. One of the Feet is repreſented by itſelf at P, L is the Plate: If the Light reflected by the Air, lying between the Glaſſes, comes to the Eye at O, there will appear a black Spot, and the Colours, which as you go from the Center, are ſo diſpoſed, that by Reaſon of the Repetition of Colours, they may be referred, to ſeveral Orders, which are as follow, black, blue, white, yellow, red; violet, blue, green, yellow, red; purple, blue, green, yellow, red; green, red; which Colours are alſo ſurrounded with other Colours, growing weaker and weaker the farther they are from the Center. 3621. Pl. 120. Fig. 2. 3622.

EXPERIMENT 2.

If the Light paſſes through the Glaſſes, and the Plate of Air which is between into the Eyes, the Spot in the Middle, through which Rays of all Colours paſs, appears white, and in receding from the Center, the Colours, which alſo may be refer'd to different Orders, oppoſite to the foregoing ones, appear according to this Series. 3623.

White, yellowiſh, red, black, violet, blue; white, yellow, red, violet, blue; green, yellow, red, bluiſh green; red, bluiſh green; which are alſo encompaſſed with weaker Colours. 3624.

In theſe two Experiments, the Orders of the Colours are eaſily perceived, if the Glaſſes of Teleſcopes of only thirty Feet be made uſe of; but the Colours are not ſo eaſily diſtinguiſhed in their Orders, except there be Glaſſes of Teleſcopes of 200 Feet or more; 3625.

but theſe being wanting, we may diſtinguiſh the ſame Colours by another Method.

EXPERIMENT 3.

3626. The right-angled Priſms abovemention'd *, are joined together,
* 3552. as was there ſaid, without putting Papers between, as in the Experiment N° 3570. The Surface of the Priſms are never ſo perfectly plane, as to touch one another every where, when applied together ; there is only immediate Contact in one Place, and there the Spot appears black by reflected Rays.

The Priſms muſt be ſo preſſed together by Screws, that the Spot may be placed in the Middle of the Surfaces applied together, and the Compreſſion may be very cloſe ; then the Spot is ſurrounded by oblong Rings, in which the Colours are diſtinguiſhed, where the Rings are broader, which obtains at the Extremities of the Axes of the greater Rings.

3627. If we obſerve the Rings, Rays being tranſmitted, what was
* 3623. mentioned in the laſt Experiment but one *, is again diſcovered ; and the Colours are ſeparated more.

3628. Theſe Colours do not depend upon a peculiar Property of the Air ; it is well known that very thin Plates of Glaſs or Water, are tinged with Colours : But we ſee diſtinctly theſe Colours in Water, by the following Method.

EXPERIMENT 4.

3629. A thin Plate of Water is made, if the Water be made thick a little with Soap, and be blown up into a Bubble through a Pipe. A Glaſs Plate is applied to a black Plane, and the Bubble is put upon that, in ſuch Manner, that it makes the Figure of an Hemiſphere. This Bubble is covered by a ſmall Glaſs Bell, which is very tranſparent, leſt by the Agitation of the Air, the Colours, which are obſerved in this Bubble, be confuſed by the Motion of the Water ; ſuch a Bubble is thinneſt at Top, becauſe the Water continually flows down towards all the Parts, and the Thickneſs is increaſed continually as you deſcend, and the Thickneſs of the whole from the ſame Cauſe, is every Moment diminiſhed. Before the Bubble is broke, it is ſo thin in the upper Part, that it tranſmits all the Light, and appears black : If in this Caſe, the Bubble be obſerv'd by reflected Rays, whilſt it is illuminated by a white Sky, and the extraneous Light is intercepted by any black Body, plac'd beyond the Bubble ; the ſaid black Spot is ſurrounded

rounded by the ſame colour'd Rings, and diſpoſed in the ſame Order, as thoſe obſerved in the black Spot, in the firſt Experiment, As the Water deſcends, the colour'd Rings are continually dilated till the Bubble is broke. Care muſt alſo be taken, that extraneous Objects do not appear in the Bubble itſelf, as in a Mirror; for by theſe, the Rings are in a Manner interrupted.

Experiment 5.

If, when the Extremity of the Bubble appears by reflected Rays, a Spectator beholds it by tranſmitted Rays, it will be blue; and in general, the Colours by tranſmitted and reflected Rays, are in the ſame Manner oppoſite to the Colours of the foregoing Experiment, as the Colours are oppoſite in the two firſt Experiments. 3630.

From theſe Experiments compared, it follows that *by increaſing the Thickneſs of a very thin Plate, it's Colour is alter'd*, and indeed that *there are ſucceſſively the ſame Alterations in the ſame Order, whether the Medium of which it is made, has a greater or leſs refracting Force*; for in a Plate of Air between the Glaſſes, and a Plate of Water in the Bubble, the Thickneſſes of which increaſe, in receding from the Middle Point, the Colours are placed in the ſame Order. 3631.

Yet *in a more refracting Plate, a leſs Thickneſs is required, than in a leſs refracting one, that they may be tinged with the ſame Colour.* 3632.

Experiment 6.

The ſame Things being given, which were mentioned in the firſt and third Experiments of this Chapter; if a ſmall Quantity of Water be put between the Margins of the Glaſſes on one Side, by little and little it penetrates between them; and in the Water there are no other Colours obſerved than in the Air, neither is the Order of them altered, but the Circles are contracted: When the Water has come to the Center, all the Portions of the Circles in the Water, are ſeparated from the Portions of the Air, and reduced into a leſs Space. 3633.

The Colour of a Plate depends upon it's Thickneſs and refracting Force, not upon the Medium ſurrounding it. 3634.

Expe-

EXPERIMENT 7.

3635. If a Plate of thin Glaſs, be ſo thin as to appear coloured, the Colours are not altered, if it be made wet; that is, if the Plate be
3636. ſurrounded with Water, inſtead of Air, *the Colour of the ſame Plate is ſo much the more vivid, as it's Denſity differs more from the Denſity of the circumambient Medium.*

3637. This is proved by Experiments already explained; for the Colours of a Plate made wet are more faint, than of the ſame Plate ſurrounded with Air. The Colours in the Plate of Water are alſo leſs vivid, which is ſurrounded with Glaſs, than that which is ſurrounded with Air; but Water and Glaſs differ leſs in the refracting Force, than Air and Water.

3638. *If Mediums equally differ in their refracting Force, the Colours will be more vivid, if the more refracting Medium be encompaſſed with the leſs refracting one*, for in a very thin Glaſs Plate, which is tinged with Colours, becauſe of it's Thinneſs encompaſſed with
* 3621. Air, the Colours will be more vivid, than in the Experiment *, in which the Plate of Air is ſurrounded with Glaſs.

3639. *A Plate of the ſame Matter, encompaſſed with the ſame Medium,*
3640. *reflects ſo much the more Light as it is thinner*; yet *if the Thickneſs*
3641. *be too much leſſened, it does not reflect the Light.* Theſe Things are evident from the foregoing Experiments, in which, the leſſer coloured Circles, which are the thinneſt too, reflect the Light the beſt of any; but in the Center, where the Plate is the thinneſt of all, there is no ſenſible Reflection; as clearly appears in the fourth Experiment. In the three firſt, there is alſo a very thin Plate of Air, which does not reflect the Light, for the tranſparent Spot is bigger than thoſe Parts of the Surfaces of the Glaſſes, which immediately touch, by the yielding of the compreſſed Parts inwards.

3642. *If there are Plates of the ſame Medium, whoſe Thickneſſes are in an arithmetical Progreſſion* of the natural Numbers, 1, 2, 3, 4, 5, 6, 7, &c. *If the thinneſt of them all reflects any homogeneous Rays, the ſecond will tranſmit the ſame*, the third will reflect them again, *and the Rays will be alternately reflected and tranſmitted*; that is, the Plates, whoſe Thickneſſes anſwer to the odd Numbers, 1, 3, 5, 7, &c. of the arithmetical Progreſſion aforeſaid, reflect the Rays, which the others tranſmit, whoſe Thickneſſes anſwer to the even Numbers, 2, 4, 6, 8, &c.

3643. This Property of the Plates, obtains in reſpect of any Sort of homogeneous Rays, with this Difference, that there are different

Thickneſſes required for different Colours, as has been already ſaid, *; the leaſt of all is for the Reflection of the violet Colour, and the Thickneſs for reflecting the red is greateſt; if the Thickneſſes are intermediate, the Rays of an intermediate Refrangibility are reflected, that is, *as the Refrangibility of the Ray increaſes, the Thickneſs of the Plate which reflects it is leſſened.* * 3631. 3644.

EXPERIMENT 8.

This Experiment is made in a dark Place, to produce the oblong Images of the Sun ſo often mentioned, upon a Paper *. Let there be, as in N. 3621, two object Glaſſes of long Teleſcopes, preſſed together, but gently that the Parts may not yield inwards, and the Eye ſo diſpoſed, that the Rays proceeding from the Image may enter into the Eye, reflected ſomewhat obliquely by the Glaſſes, that the Eye may ſee all the Colours of the ſaid Image ſucceſſively, as in a Mirror; that is, that the Glaſſes may be ſucceſſively enlightened by different homogeneous Rays; which may be done by gently moving the Priſm about it's Axis, by which the Rays are ſeparated in the oblong Image. The Rings mentioned in the firſt Experiment appear, but in greater Number, and only of one Colour, becauſe of the Immutability of the Colour in the homogeneous Rays *, in the Interſtices of thoſe Rings the Rays are tranſmitted, as appears from the Blackneſs; it is alſo immediately demonſtrated, if the Rays fall upon the Glaſſes themſelves; for thoſe, which paſs through the Separations of the Rings, give Circles of the ſame Colour on Paper, placed behind the Glaſſes; the Rings are the leaſt of all, when they are violet, then they are ſucceſſively dilated, conſidering the following Colours, quite to the red. Theſe Things are demonſtrated diſtinctly with the Priſms *, but the Glaſſes muſt be ſpherical, and but a little convex, that what follows may appear. 3645. * 3484. * 3513. * 2626.

If when the Rings are of any Colour, the Glaſſes and the Eye remaining fixed, you meaſure exactly the Diameters of the Circles, that may be conceived to be in the Middle of the Breadth of the Rings, the Squares of the Diameters will be to one another, as the odd Numbers 1, 3, 5, &c. And in the ſame Manner if the Diameters of the Circles be meaſured, which are in the Middle of every one of the Interſtices between the Rings, the Squares of their Diameters will be as the even Numbers 2, 4, 6, &c. but in Glaſſes that are ſpherical, the Squares of the Diameters are as the Thickneſs of the Plate of Air, in the aforeſaid Circle, that is, theſe Thickneſſes are as the even and odd Numbers. 3646.

DEFI-

DEFINITION

3647. *An homogeneous Colour in a Plate of any Medium, is ſaid to be of the firſt Order, if the Plate be the thinneſt of all thoſe that reflect that Colour; in a Plate, whoſe Thickneſs is triple, it is ſaid to be of the ſecond Order*, &c.

3648. *A Colour of the firſt Order is the moſt vivid of any, and ſucceſſively in the following Orders, in the ſecond, third, &c. it is leſs and leſs*

* 3639. *vivid**.

3649. When a Plate of Air is enlightened with heterogeneous Rays, as that between the Glaſſes of the Teleſcopes, or any Plate like it, of any other Matter, as N. 3629, ſeveral of the Rings ſeen in the Experiment N. 3645, are confuſed, and that Colour is ſeen,

3650. which is made of their Mixture; for *the ſame Thickneſs of a Plate is often required for reflecting different Colours of different Orders:* Thus a Plate which reflects the violet of the third Order, does alſo reflect the red of the ſecond Order, as may be gathered from the laſt Experiment, if it be attentively conſidered: And therefore, in N. 3622. 3629. the third violet Ring is confounded with the outward Edge of the ſecond red Ring, and a purple Colour is produced; yet all the red of the ſecond Order is not abſorbed, becauſe the red Ring is wider than the violet Ring.

3651. *The more the Thickneſs of a Plate is encreaſed, the more Colours it reflects, and various ones too*, of different Orders. The violet Plate of the tenth Order, agrees with the blue one of the ninth, and the yellow one of the eighth Order, and laſtly, with the red one of the ſeventh Order, and the Colour of the Plate conſiſts of the Mixture of theſe Colours.

3652. *If* in the firſt and fourth Experiments of this Chapter, *a Spectator looks obliquely upon the Plates*, ſuch as that made of Air, and that made of Water, the Rings will be dilated, as they are ſeen more obliquely, that is, in this Motion of the Eye, *the Colour of the Plate is changed* in a determinate Place; yet the Dilatation is greater in

3653. N. 3621, which proves that *the Colour is more changed by the Obliquity of the Rays, if the Plate be encompaſſed with a more refracting Medium, than if it is encompaſſed by a leſs refracting one.*

3654. The Demonſtration of which Propoſition is eaſily deduced from

Plate 120. Fig. 3. the Laws of Refraction. Let L and *l* be thin Plates; the laſt encompaſſed with a more refracting Medium, and the firſt with a leſs refracting Medium, and let them both be of the ſame Thickneſs: If the Rays A B, *a b*, equally inclined to the Plates, fall

upon them, there will be a Refraction at L, towards the Perpendicular *, on the contrary at *l* the Ray is refracted from the Perpendicular †; and though BD and *b d* are equal, *bc* is longer than BC; and therefore there is a greater Change in the Motion of the Light in the Plate *l* than in L. * 2787.2840. * 2783.2840.

The refracting Force of the Plate L *being increaſed, the leſs refracting Medium with which it is encompaſſed remaining, there will be a leſs* Difference between BC and BD, and ſo a leſs *Change of Colours*; and *if the refracting Power of the Plate be augmented*, ſo that the refracted Rays, whatever be the Obliquity of the incident ones, ſhall not ſenſibly Differ, *there will be no ſenſible Difference in the Colour of the Plate, whatever Situation the Eye is placed in.* 3655. 3656.

From hence we deduce, that *the Colour of ſome Plates will vary upon changing the Poſition of the Eye, and that the Colour of others is permanent.* 3657.

CHAP. XXVI.

Of the Colours of natural Bodies.

WHAT regards the Colours of all Sorts of Bodies, may eaſily be deduced, from what has been already explained. 3658.

The reflected Rays are to be firſt examined, and the Make of the Surfaces muſt be inquired into.

We have ſhewn that the Rays of Light have Colours peculiar to themſelves, and unchangeable, ſo as not to be changed by Reflection *. * 3537.

Therefore *the Rays reflected from Bodies, have a greater or leſs Refrangibility, according as a greater or leſs Refrangibility is proper to the Colour of the Body itſelf.* 3659.

EXPERIMENT I.

Let two ſquare Pieces of Ribbon, or Cloth, the one red, and the other blue, be fixed in the Middle of a black Paper, and ſo join'd as to touch one another at their Sides. Place the Paper ſo, as that the Ribbons may be well enlightened by the Light which comes through a Window into a Room; if a Spectator looks at the Ribbons through a Priſm, the Colours will appear ſeparated. But the Experiment anſwers better if it be made as the ſecond Experiment of the twenty ſecond Chapter; then the ſaid Pieces of Ribbon, 3660. Pl. 121. Fig. 1.

bon, or Cloth, are applied to the Ruler L L; alſo the painted Spots of the ſaid Colours, if theſe be intenſe may be made uſe of: They are illuſtrated with Light reflected from a Mirror, the other
* 3545. Things were ſhewn in the ſaid Experiment *, and the Succeſs is
* 3543. the ſame *.

Experiment 2.

3661. This Experiment is made in the ſame Manner as the third Ex-
Plate 121. periment of the twenty ſecond Chapter; but inſtead of the black
Fig. 2. Lines, we make uſe of a black ſilken Thread, which we wind about the Ruler L L in ſuch Manner, that the black Lines may truly paſs through the coloured Surfaces, which are illuminated with Light reflected from the Mirror, inſtead of the coloured Image, which is made uſe of in the ſame Experiment. The Spots are repreſented upon a Paper *t*, as in the ſaid Experiment; alſo, as there, the white Paper muſt be placed at a leſs Diſtance, that we may have an exact Repreſentation of the blue Spot: We eaſily diſcover when the Repreſentations are exact, for the Threads appear diſtinct.

3662. *That Bodies have various Colours, becauſe different Rays are reflected from Bodies of different Colours, and that a Body appears of that Colour which ariſes from the Mixture of the reflected Rays*, is not only deduced from the foregoing Experiments, but may alſo be demonſtrated directly by the 1ſt Experiment, Chap. 22. From whence it follows, that natural Bodies reflect Rays of all Colours, but ſome in a greater Plenty; and theſe only are ſenſible, when Bodies are enlightened with heterogeneous
* 3538. Light *. The Rays which are not reflected from a Body, pene-
3663. trate into it, and there ſuffer innumerable Reflections and Refrac-
* 3448. tions, till at laſt they unite themſelves to the Particles of the Body
3664. itſelf; therefore *a Body grows hot ſo much the ſooner, as it reflects*
* 3397. *Light in a leſs Quantity*; therefore *a white Body*, which reflects
3665. almoſt all the Rays with which it is enlightened*, *heats the ſloweſt,*
* 2421. *whilſt a black Body*, into which almoſt all the Rays penetrate, be-
† 3563. cauſe only a few are reflected †, *acquires Heat ſooner than any other.*

3666. In Order to determine the Conſtitution of the Surfaces of Bodies, upon which their Colour depends, we muſt conſider the ſmalleſt Particles of which thoſe Surfaces are formed; theſe Par-
* 3443. ticles are tranſparent*, and are ſeparated by a Medium of a different
* 3448. refracting Force, from the Particles themſelves *; they are alſo thin,

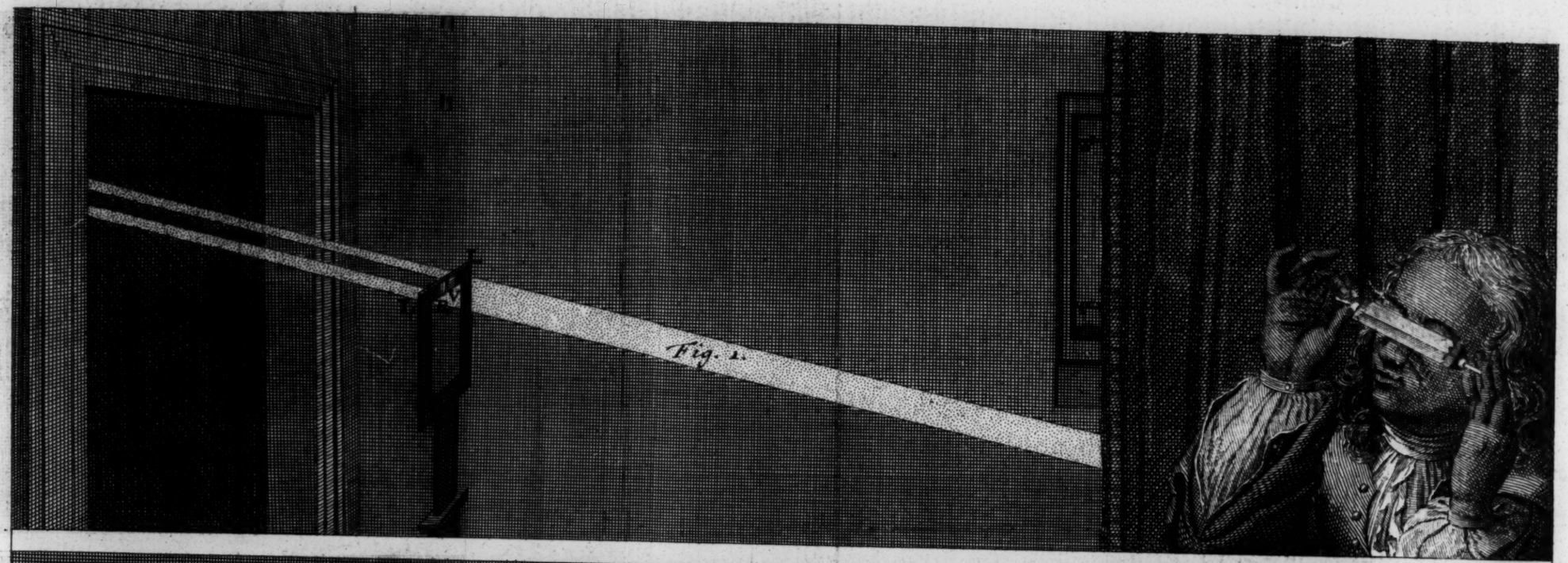


Fig. 1.

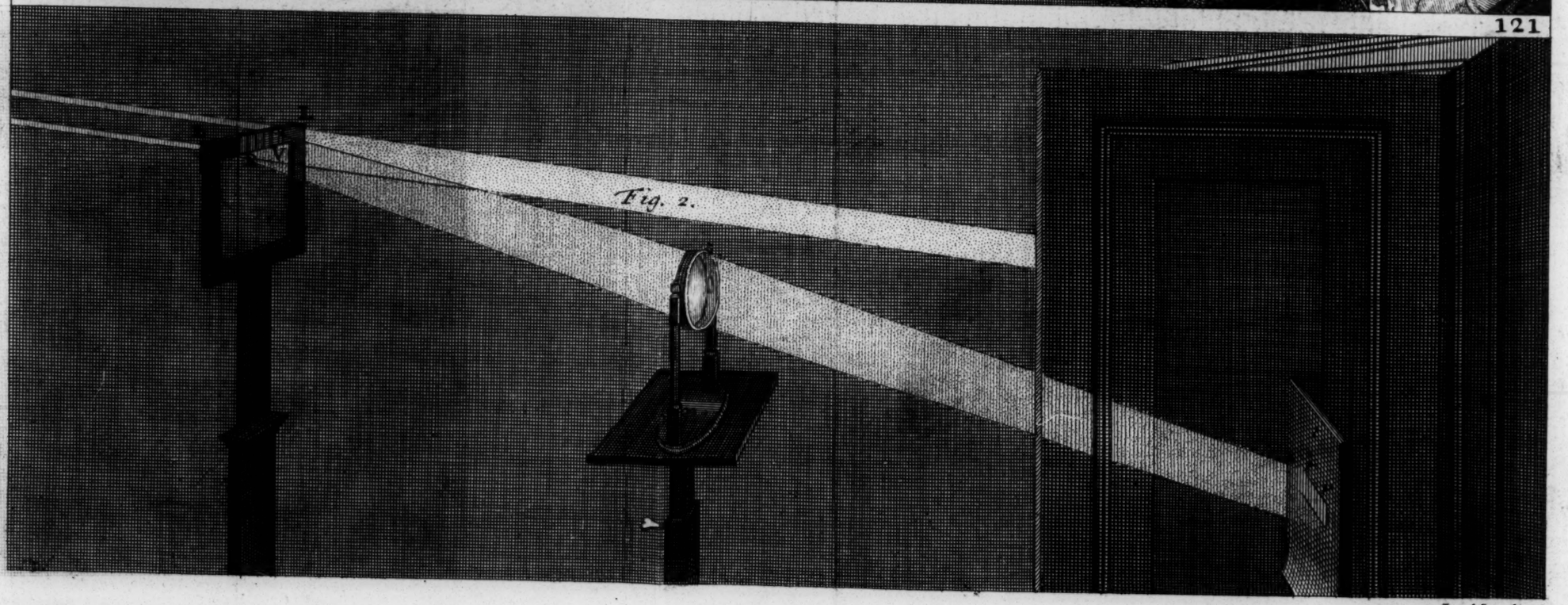


Fig. 2.

J. Mynde sc.

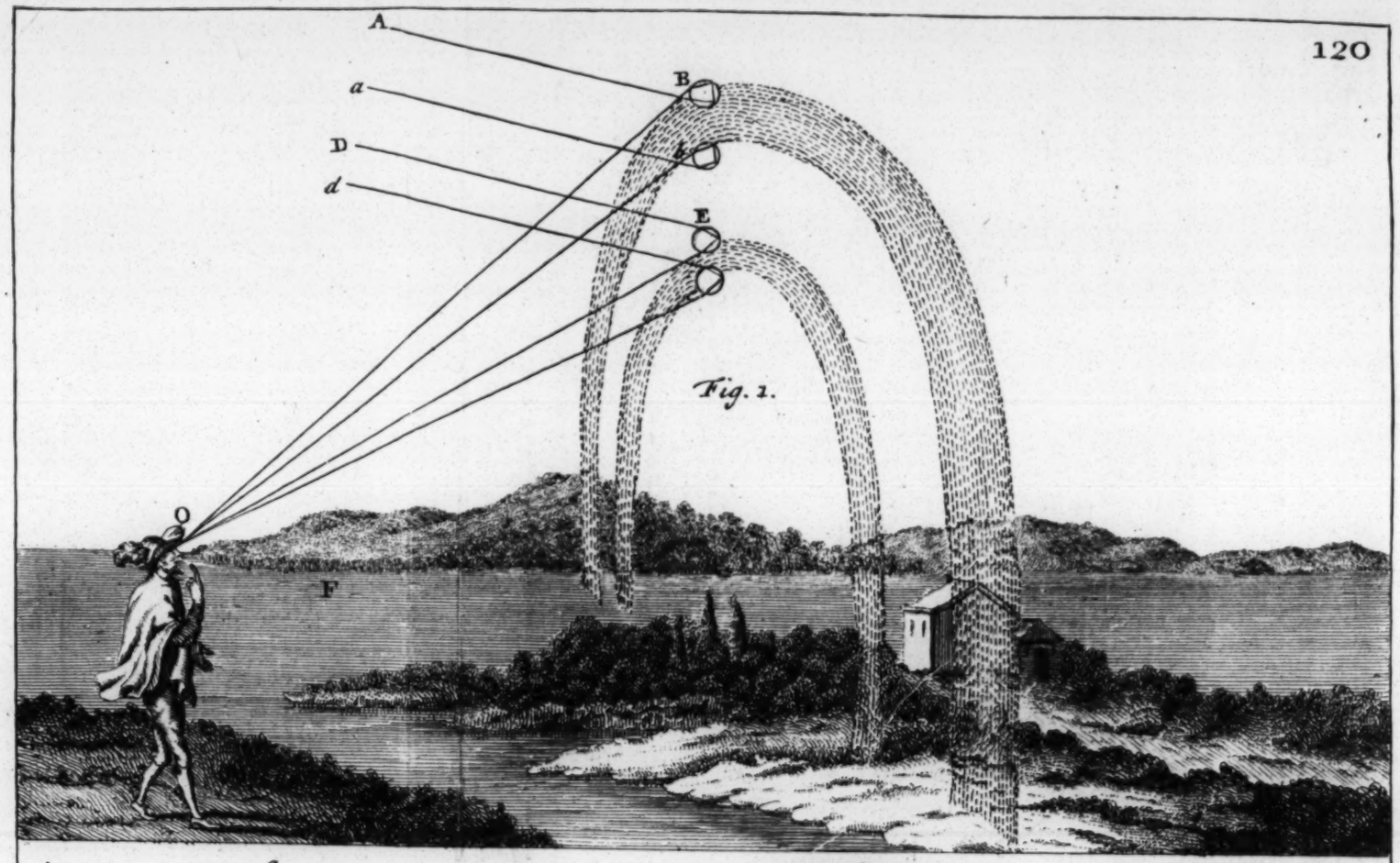


Fig. 1.

Fig. 3.

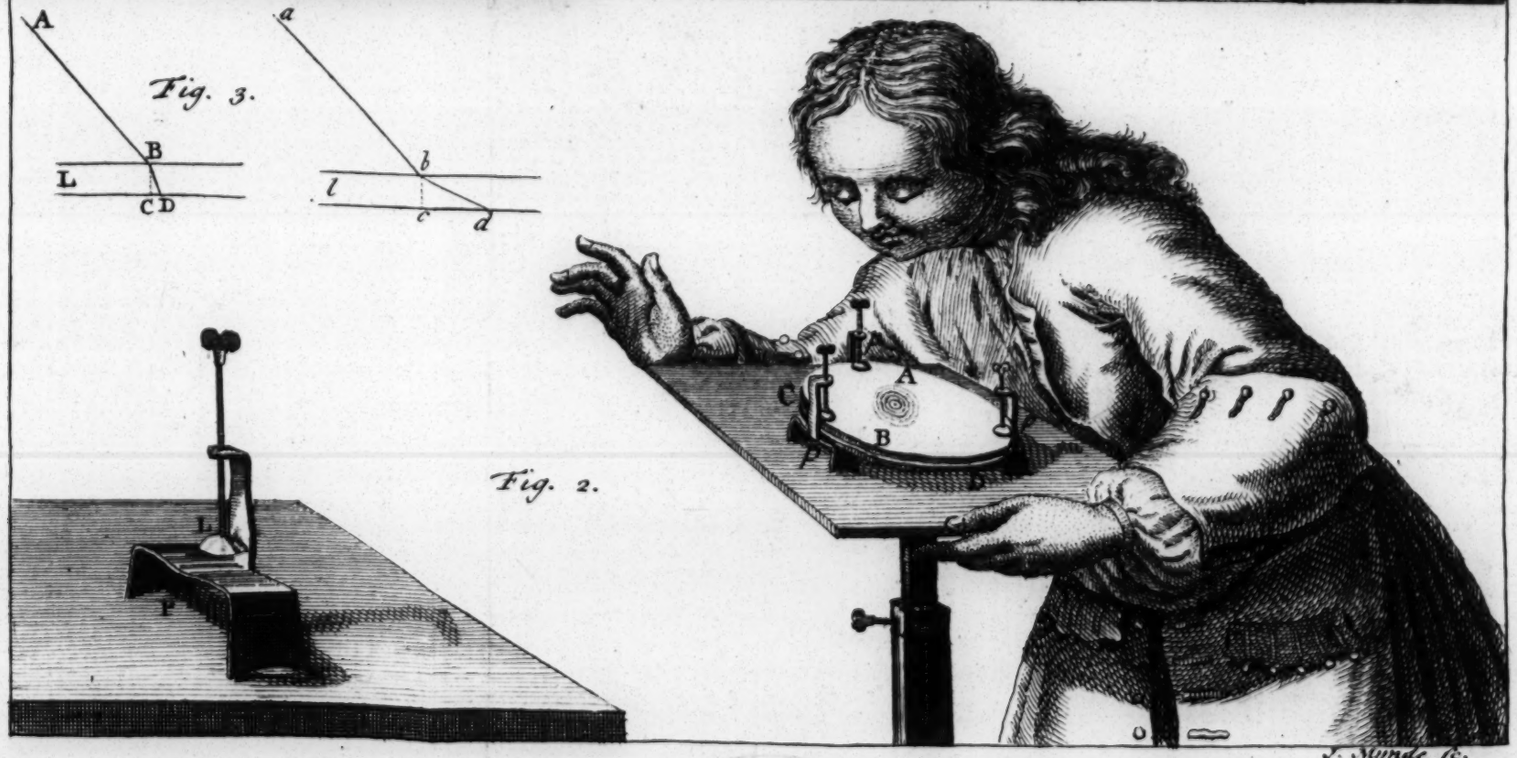


Fig. 2.

J. Mynde fc.

otherwiſe the Surface would as it were be covered with a tranſparent Body *, and the Colour would depend upon the Particles underneath theſe: Therefore there are innumerable ſmall thin Plates in the Surface of every colour'd Body; but by leſſening the Plate, when the ſame Thickneſs is preſerved, it's Properties with regard to the Reflection of Light are not alter'd; for the ſmalleſt Plate is very large in reſpect to the Rays of Light; therefore what has been demonſtrated in the laſt Chapter may be applied to theſe Plates, in the Surfaces of Bodies, from whence we deduce the following Concluſions. * 3449. 3667. 3668.

The Colour of a Body depends upon the Thickneſs and refracting Force of the Parts of the Body, which are in the Surface between the Pores of the Body *. 3669. * 3634.

*The Colour is ſo much the more vivid and homogeneous, as the Parts are thinner**. 3670. * 3648.3651.

Cæteris paribus, the aforeſaid Parts are of the greateſt Thickneſs when the Body is red; and of the leaſt when it is violet *. 3671. * 3643.

*The Parts of Bodies are of a much greater refracting Force, than the Medium contained in their Interſtices**. 3672. * 3653.3655. 3656.

This refracting Force is leſs in the Tails of Peacocks, and generally in all *Bodies whoſe Colour differs according to the different Situation of the Eye* *. 3673. * 3652.3655.

The Colour of a Body is more obſcure and dark, when a more refracting Medium enters it's Pores *, for then the Parts, upon which the Colour depends, are encompaſſed by a more refracting Medium than before. 3674. * 3656.

This is found by Experience, in all Bodies which are thoroughly penetrated by Water or Oil; when the Bodies are dry they recover their former Colour, unleſs in ſome Caſes, in which ſome Parts are carried away, by the Action of the Water or Oil, or when ſome Parts of the Water or Oil are ſo united with the Parts of the Body, as to change the Thickneſs of the Plates. 3675.

From ſuch a Cauſe are deduced the Changes in the Colours of ſome Liquors, upon mixing them with others; *the ſaline Particles ſwimming in one Liquid, often unite themſelves to the ſaline Particles ſwimming in one another; or from the Action of the ſupervenient Particles, the Particles joined together are ſeparated; by all which* the Thickneſs of the Particles, and with that *the Colour of the Liquid is changed* *. 3676. * 3631.

The Colour of a Liquid is ſometimes different, if it be ſeen by reflected Rays, from what it is when ſeen by tranſmitted ones: We have ſhewn before how this happens *. 3677. * 3622.3624.

EXPERIMENT 3.

3678. An Infuſion of *Lignum Nephriticum*, not too much tinged, appears blue by reflected Rays, but yellow when the Vial containing it is between the Eye and the Light.

EXPERIMENT 4.

3679. If Spirit of Vinegar be poured into the Infuſion of *Lignum Nephriticum*, it appears yellow whereſoever it be ſeen.

3680. In that caſe the Thickneſs of the Particles is changed, and the Rays that were tranſmitted through each of the Particles are intercepted; but though the Liquor is placed between the Eye and the Light, it is ſeen by reflected Rays; for we may eaſily conceive that ſuch Rays come to the Eye from the various Reflections which the Light ſuffers in the Liquid. But this Colour only is ſenſible, becauſe the Rays cannot penetrate directly through the Liquid.

3681. From this we may deduce the Reaſon why *a coloured Liquid, in a Glaſs of the Figure of an inverted Cone, when it is placed between the Eye and the Light, appears of a different Colour in different Parts of the Veſſel*; in the lower Part all the Rays which are tranſmitted through the Particles are not intercepted; then they are more and more intercepted, according as there is a greater Quantity of the Liquid between the Eye and the Light; at laſt they come to be all intercepted, and only thoſe which are reflected by the Particles do penetrate into the Liquid; in which Caſe the Colour coincides with the Colour of the Liquid ſeen by the reflected Rays.

3682. Oftentimes *the Clouds appear with very beautiful Colours.* They conſiſt of aqueous Particles, between which Air is interſperſed; conſequently a Cloud will be of a different Colour, *according to the va-*

* 3631. *rious Thickneſs of theſe aqueous Particles* *.

The End of the FIFTH BOOK.

Mathematical Elements

OF

NATURAL PHILOSOPHY

CONFIRM'D BY

EXPERIMENTS.

BOOK VI.

PART I. Of the Syſtem of the World.

CHAP. I.

A general Idea of the Planetary Syſtem.

HE, who attentively conſiders that Space can be terminated by no Bounds *, will ſcarce be able to deny, that the ſupreme Almighty Intelligence has every where manifeſted the ſame Wiſdom, which he has ſhewn to the Inhabitants of the Earth in a ſmall Compaſs. What I here call a ſmall Compaſs immenſely exceeds our Comprehenſion; yet it is but ſmall, compared with infinite Space. 3683. * 27.

Our Earth, with ſixteen other Bodies (for we have no Knowledge of any more) *moves in a determinate Space*; neither do theſe Bodies recede from, or come nearer to one another, beyond their ſet Bounds; *and their Motions are performed according to unchangeable Laws.* 3684. 3685.

DEFI-

DEFINITION 1.

3686. *This Collection of ſeventeen Bodies is called the Planetary Syſtem.* The
3687. whole Art of Aſtronomy is almoſt employed concerning theſe alone; and theſe will be chiefly my Subject in this Book: The other Bodies that conſtitute the Univerſe are too far diſtant from us for their Motions (if they are mov'd) to fall under our Obſervations: Of theſe only the lucid Bodies can be perceived by us; and of theſe only the moſt remarkable ones, and which are leſs diſtant from us than the reſt, even moſt of ſuch as are ſeen by the Teleſcope, are inviſible to the Eye.

DEFINITION 2.

3688. *All theſe Bodies are called fixed Stars.*
3689. They are called fixed, becauſe, as far as can be perceived, they keep the ſame Poſition, with reſpect to one another: We muſt take Notice of ſomething peculiar concerning theſe hereafter.
3690. But as to the planetary Syſtem: *In this* we have ſaid *there are* ſeventeen *Bodies, which are all ſpherical: One only ſhines by it's own Light, the reſt are opaque, and are viſible only by the Light which they borrow from that.*
3691. *The Sun is that lucid Body, and far the greateſt of all in the planetary Syſtem; it is quieſcent in the Middle of it,* at leaſt is agitated by a very ſmall Motion.

DEFINITION 3.

3692. The other ſixteen are called Planets.
3693. *Theſe are divided into two Claſſes; ſix are called the* primary Planets; *ten are called the* ſecondary Planets. When we ſpeak of the Planets, without any Diſtinction, we always underſtand the primary ones.
3694. *The primary Planets move round the Sun,* and are carried at different Diſtances from it, in Curves that return into themſelves.
3695. *A ſecondary Planet revolves round a primary one,* and accompanies it in it's Motion round the Sun.
3696. *The Planets in their Motions deſcribe elliptic Lines* *, not much
* 625. different from Circles. *And* all *thoſe* Lines *are fixed,* at leaſt, there is but a ſmall Change to be obſerved in a long Time, in their Situation.
3697. *The Orbits of all the primary Planets are in ſuch a Poſition that one*
Plate 126, *of their Foci falls in with the Center of the Sun;* let the Ellipſe
Fig. 3. AB

A B *a b* repreſent the Orbit of a Planet, F will be the Center of the Sun.

Definition 4.

The Diſtance between the Center of the Sun, and the Center of 3698.
the Orbit, is called the Excentricity of the Planet; as F C.

In every Revolution the Planet approaches once to the Sun, and 3699.
once recedes from it; and it's greateſt Diſtance is at *a*, the Extremity of the greater Axis of the Orbit, and it's leaſt Diſtance in the oppoſite Extremity A.

Definition 5.

That Diſtance of the Planet from the Sun is called the mean Diſtance, 3700.
which is equally different from the greateſt and the leaſt.

At this Diſtance the Planet is in the Extremities B, *b*, of the 3701.
ſmaller Axis.

Definition 6.

The Point of the Orbit, in which the Planet is at it's greateſt Di- 3702.
ſtance from the Sun, is called the Aphelium; as *a*.

Definition 7.

The Point of the Orbit, in which the Planet is at it's leaſt Di- 3703.
ſtance from the Sun, is called the Perihelium; as *a*.

Definition 8.

Theſe Points are commonly called the *Auges* or *Apſides*. 3704.

Definition 9.

The Line which joins the Apſides, that is, the greater Axis of 3705.
the Orbit, *is called the Line of the Apſides.*

Every Orbit is in a Plane, which paſſes through the Center of 3706.
the Sun.

Defninition 10.

The Plane of the Orbit of the Earth is called the Plane of the 3707.
Ecliptic.

This Plane is to be continued every Way; and *Aſtronomers* con- 3708.
ſider the Poſition of the Planes of the other Orbits, with reſpect to this.

Defi-

DEFINITION 11.

3709. *The Points, in which the other Orbits cut the Plane of the Ecliptic, are called the Nodes.*

DEFINITION 12.

3710. *The Line which joins the Nodes of any Orbit*, that is, the common Section of the Plane of the Orbit, with the Plane of the Ecliptic, *is called the Line of Nodes.*

3711. *A Planet is not carried with an equal Celerity in all the Points of*
3712. *it's Orbit; the leſs it is diſtant from the Sun, the ſwifter is it's Motion; and the Times, in which the ſeveral Archs of it's Orbit are run through, are to one another, as the Area's formed by Lines drawn from the Planet to the Center of the Sun*; the Archs A B and D *d* are run through in Times, which are to one another, as the Area's of the mix'd Triangles A F B, D F *d*.

3713. *All the Planets are carried the ſame Way*, and their Motion in their
3714. Orbits is contrary to that Motion which we obſerve daily in all the cœleſtial Bodies, by which in one Day they ſeem to be carried round the Earth; of which hereafter.

DEFINITION 13.

3715. *A Motion, ſuch as is that of the Planets in their Orbits, is ſaid to be* in Conſequentia, and direct.

DEFINITION 14.

3716. *The contrary Motion is called a Motion* in Antecedentia; *and ſometimes* retrograde.

3717. *The more diſtant the Planets are from the Sun, the ſlower they move in their Orbits*; ſo that the periodical Times of the moſt diſtant ones are greater, both becauſe they have a greater Orbit to run through, and a ſlower Motion.

DEFINITION 15.

3718. *The Line which paſſes through the Center of the Planet, and about which it moves, is called the* Axis of the Planet.

3719. *The Planets*, at leaſt moſt of them, *and the Sun itſelf move round their Axes:* There are two, of which, in this Reſpect, Aſtronomers have been able to make no Obſervations, but which, in all Probability, have this Motion.

This Motion agrees or conſpires with the Motions of the Planets in their Orbits, that is, it *is in Conſequentia.* 3720.

The Axes themſelves *are mov'd by a parallel Motion*, ſo that all the Points of the Axis of a Planet deſcribe equal and ſimilar Lines. 3721.

Definition 16.

The Extremities of the Axis are called the Poles of the Planet. 3722.

Aſtronomers compare together accurately enough the Diſtances of the Planets from the Sun, to give us an Idea of the whole Syſtem; the Dimenſions of the Orbits are repreſented in this Scheme, in which the Points N, N ſhew the Nodes of each Orbit. 3723. Plate 122. Fig. 1.

Nevertheleſs, *we cannot compare the Dimenſions of the Syſtem with any Meaſure that we know upon the Surface of the Earth*; for no Aſtronomers will aſſert that the Obſervations made concerning ſuch a Compariſon are free from Error. 3724.

But, that the ſeveral Parts of the Syſtem may be compared together, we ſuppoſe the mean Diſtance of the Earth from the Sun divided into a thouſand equal Parts, which we make uſe of in meaſuring the other Diſtances. 3725.

The Sun ☉, as was ſaid before, is agitated by a ſmall Motion in the Middle of the Syſtem: it moves round it's Axis, in the Space of 25 Days and an half; and it's Axis is inclined to the Plane of the Ecliptic, making an Angle of 87 Deg. 30 Min. 3726.

Mercury ☿, is the leaſt diſtant from the Sun of any of the Planets; it's mean Diſtance from the Sun is 387, it's Excentricity 80, the Inclination of it's Orbit, that is the Angle, formed by the Plane of it's Orbit with the Plane of the Ecliptic, is 6 Deg. 52 Min. it performs it's Revolution round the Sun in 87 Days, 23 Hours, 15′. 38″. 3727.

The next is *Venus* ♀, whoſe mean Diſtance from the Sun is 723, it's Excentricity 5, the Inclination of it's Orbit 3 Deg. 23 Min. It performs it's periodical Motion in 224 Days, 14 Hours, 49′, 20″, and it's Motion round it's Axis is performed in 24 Days, 8 Hours. It's Axis makes an Angle with the Plane of the Ecliptic of 15 or 20 Deg. 3728.

The third Planet in Order from the Sun is our Earth ☉; it's mean Diſtance from the Sun is 1000, it's Excentricity 16, 91, or 17 nearly, it is moved in the Plane of the Ecliptic, it's periodical Time is 365 Days, 6 Hours, 59′, 14″. This exceeds the tropical Year 29′, 17″, and the Motion about it's Axis is performed in 23 Hours, 3729.

56 Min. 4 Seconds; it's Axis makes an Angle with the Plane of the Ecliptic of 66 Deg. 31 Min.

3730. The mean Diſtance of *Mars* ♂ from the Sun is 1524, it's Excentricity 141, the Inclination of it's Orbit 1 Deg. 52 Min. it's periodical Time 686 Days, 22 Hours, 29′. it's Revolution about it's Axis is performed in 24 Hours, 40 Min.

3731. *Jupiter* ♃, the biggeſt of all the Planets is diſtant from the Sun, at a mean Diſtance 5201, it's Excentricity 250, the Inclination of it's Orbit 1 Deg. 20 Min. the periodical Time 4332 Days, 12 Hours, 20′. 9″. and it's Revolution about it's Axis S performed in 9 Hours, and 56 Min.

3732. The mean Diſtance of *Saturn* ♄, the moſt diſtant Planet from the Sun is 9538, it's Excentricity 547, the Inclination of it's Orbit 2 Deg. 30 Min. the periodical Time 10759 Days, 6 Hours, 36′. It is encompaſſed with a Ring, which does not touch the Planet, but never leaves it: This Ring is not viſible without a Teleſcope.

3733. The mean Diſtance being given, if you add the Excentricity, you will have the greateſt Diſtance; but if you ſubſtract the Excen-
* 3698. tricity from the mean Diſtance, you will have the leaſt Diſtance*.

3734. The three Planets, *Mars*, *Jupiter* and *Saturn*, which are more
3735. diſtant from the Sun than the Earth, are called the *ſuperior Planets*; *Venus* and *Mercury* are called the *inferior ones*.

3736. *Of the primary Planets, three are accompanied with ſecondary ones.*

3737. Five Planets, called the Satellites, move about *Saturn*, four about *Jupiter*; one about the Earth (viz.) the Moon.

3738. The ſecondary Planets, except the Moon, are not viſible to the naked Eye.

3739. *The Satellites, by Lines drawn to the Center of the primary Planets, deſcribe Area's about them, proportional to the Times*; as has been ſaid of the primary Planets, with Reſpect to the Center of
* 3712. the Sun*.

3740. *The Moon moves about the Earth in an Ellipſe, one of whoſe Foci is in the Center of the Earth*, from which the mean Diſtance of
3741. the Moon is 60 Semidiameters of the Earth and an half: *It's Excentricity is liable to change*; the mean one is of three Semi-diame-
3742. ters and a third. The Plane *of it's Orbit* forms an Angle with the Plane of the Ecliptic of 5 Degrees, *but this Inclination is not con-*
3743. *ſtant, or always the ſame.* [*In the Motion of the Moon round the Earth, neither the Line of the Nodes, nor the Line of the Apſides,*

is carried in a parallel Motion; but the *Line of the Nodes*, Weſtward, or in *Antecedentia*; *the Lines of the Apſides* Eaſtward, or in *Conſequentia*; the firſt performs it's Revolution in about nine Years, the ſecond in 19. The periodical Time of the Moon's Motion about the Earth is 27 Days, and about 7 Hours, 43 Min. and it is turned about it's own Axis exactly in the ſame Time.

The firſt or inmoſt of the Satellites of *Jupiter* is diſtant from *Jupiter*'s Center $2\frac{5}{6}$ Diameters of *Jupiter*, it is moved round *Jupiter* in one Day, 18 Hours, 27 Min. 34 Seconds. 3744. Plate 122. Fig. 2.

The Diſtance of the ſecond is four and an half Diameters of *Jupiter*: It's periodical Time is 3 Days, 13 Hours, 13′, 42″.

The Diſtance of the third is $7\frac{1}{6}$ Diameters; it's periodical Time 7 Days, 3 Hours, 42′, 36″.

The fourth is diſtant $12\frac{2}{3}$ Diameters: It performs it's Motion 16 Days, 16 Hours, 32′. 9″.

The firſt or inmoſt Satellite of *Saturn* is diſtant from *Saturn*'s Center $\frac{39}{40}$ of a Diameter of the Ring: It's periodical Time is one Day, 21 Hours, 18′, 27″. 3745. Plate 122. Fig. 3.

The Diſtance of the ſecond $1\frac{1}{4}$ Diameter of the Ring: It's periodical Time is 2 Days, 17 Hours, 41′, 22″.

The Diſtance of the third is $1\frac{3}{4}$ Diameter of the Ring: It's periodical Motion is 4 Days, 12 Hours, 25′, 12″.

The Diſtance of the fourth is 4 Diameters of the Ring; it's periodical Time 15 Days, 22 Hours, 41′, 14″.

The Diſtance of the fifth is 12 Diameters of the Ring; it's periodical Time is 79 Days, 7 Hours, 48′.

Concerning the Motion of theſe, as alſo of the Satellites of *Jupiter* about their Axis, we can hitherto determine nothing certain from Aſtronomical Obſervations. 3746.

If we take Notice of the Diſtances and periodical Times of the Planets, we ſhall find that the following Rule holds good in our Syſtem; wherever ſeveral Bodies are moved round the ſame Point, that is *about the Sun, Saturn and Jupiter*, (viz.) *the Squares of the periodical Times are to one another, as the Cubes of the mean Diſtance from the Center.* 3747.

To give a Notion of the Dimenſions of the Bodies themſelves in our Syſtem, we have contrived the fourth Figure, in which all the primary Planets, and *Saturn*'s Ring are deſcribed, according to their Dimenſions; the Sun, whoſe Magnitude exceeds all the reſt, is repreſented by the greateſt Circle (Fig. 1.) that is, the Circle which terminates the Figure. 3748. Plate 122. Fig. 4.

3749. Theſe Dimenſions repreſent the Proportions of the Bodies one to another exactly enough, if you except the Earth, which, for
* 3724. the Reaſon already mentioned *, cannot be ſo compared with the other Bodies, as to leave no room to doubt what Proportion it bears to them.

3750. *Yet the Earth's Diameter may be meaſured*, and contains 3389940 Perches, each of which is equal to 12 *Rhynland* Feet; but although the Diameters of the other Planets may be compared together, and with the Sun's Diameter, yet it cannot be determined how many Feet they contain, till after Obſervations ſhall be made at a proper Time hereafter.

3751. Of the Bodies that make up the planetary Syſtem, *the Moon only can be compared to the Earth*; it's Diameter being to the Diameter of the Moon, as 73 to 20.

3752. *The other ſecondary Planets are not meaſured by Aſtronomers*, but it cannot be doubted, but that ſome of them are bigger than the Earth.

Beſides the Bodies already mentioned, there are others in the planetary Syſtem, which are viſible for a Time, as they come near the Sun, and then recede from it, and become inviſible; they are
3753. called *Comets*. They *appear moſt commonly with Tails, and the Tail*
3754. *is always turned from the Sun; in their Motion they deſcribe Area's,*
3739. *by Lines drawn to the Center of the Sun, proportional to the Times,*
* 3712. as has been ſaid of the Planets *.

3755. *As to Comets, it is probable that they move in elliptic Orbits, that are very excentric*; ſo that they are inviſible, when they are in that Part of the Orbit which is moſt diſtant from the Sun; which is deduced from the Periods of ſome of them, that have been obſerved to be pretty regular: And it is plain from Obſervations, that
3756. *ſome have deſcribed in their Motion Portions of very excentric Ellipſes, in one of whoſe Foci was the Center of the Sun.*

3757. The Notion, that we have hitherto given of the planetary Syſtem, is founded upon aſtronomical Obſervations; and what we have already ſaid admits of no Diſpute among Aſtronomers, if we except what relates to the Ecliptic Line and the Motion of the Earth.

3758. Some affirm, that the Orbits of the Planets are not Elliptic, but that in their Motion they deſcribe another oval: *Kepler* has deduced from *Tycho Brahe*'s Obſervations, that theſe Lines are Elliptic; and we ſhall ſhew in the following Part, that no other Curves can be deſcribed by the Planets.

Thoſe

Jup. cum Satell.

Fig. 2.

Sat.

Venus Tell Mars

Merc

Fig. 4. Jup.

Sat. cum Satell.

Fig. 3.

Fig. 1.

Thoſe that ſay the Earth is at reſt, have no aſtronomical or phyſical Argument for a Foundation of their Opinion; that is, don't reaſon from *Phænomena:* Neglecting the Simplicity of the Syſtem, and the Analogy of the Motions, they aſſert that their Opinion is not contrary to Obſervations; in which they err, as we ſhall ſhew in the following Part. 3759.

CHAP. II.

Concerning the apparent Motion.

WHOEVER after having read the former Chapter, looks upon the Heavens, will ſcarcely believe, that he beholds the Syſtem, which is explained there; and a more exact Conſideration of the heavenly Motions will increaſe his Doubt. No Wonder, ſince *we can obſerve very little in the Heavens but falſe Appearances.* 3760. 3761.

The common Obſerver of the Heavens is a Spectator, who, thinking himſelf to be at reſt, is carried about by various Motions, and beholds Bodies, concerning whoſe Diſtance and Magnitude he makes falſe Judgments. The true Syſtem of the World was unknown for many Ages, even to the moſt exact Obſervers of the Heavens. 3762.

But we muſt explain how all Things, which are obſerved in the heavenly Bodies, have Place in the Syſtem that has been explained in Reſpect of a Spectator upon the Earth; that is, we ſhall deduce the Appearances from the known Motions. Which cannot be done, unleſs we firſt lay down ſome general Things concerning the apparent Motion in general. 3763.

It is certain, that we have no Art, by which we can diſcover the true Motion, only the relative Motion can be perceived by the Senſes *; and it is that only concerning which we treated in the former Chapter: Who can reaſonably affirm or deny, that all the Bodies, which are known to us, are not carried in a common Motion through the immenſe Spaces? 3764. * 114.

The relative Motion is to be diſtinguiſhed from the apparent one; for the apparent Motion is the Change which appears to be in the Situation of the Bodies, and depends upon the Change of the Picture in the Bottom of the Eye; for * Objects have the ſame apparent Relation to one another, as their Repreſentations have in the 3765. * 3076.

the Eye; for they are ſeen as they are painted in the Eye and the Change in that Picture, from the Motion of the Bodies, moſt commonly differs from the Change of the Relation between the Bodies themſelves; as follows from the Formation of that Picture.

3766. *The Heavens are nothing but an immenſe Space which cannot be*
* 3462. *ſeen*, and would appear black, * if innumerable Rays of Light flowing from the heavenly Bodies, did not continually penetrate our Atmoſphere. Moſt of them come to us from the Bodies in right Lines. Yet a great many ſuffer various Reflections in the Atmoſphere, and enlighten the whole Atmoſphere; which is the Reaſon that, in the Day, Bodies are enlightened, even without the Reflection of the Clouds, to which the Rays of the Sun cannot come directly.

3767. Theſe Rays are heterogeneous and white; for there are Bodies enlightened by theſe Rays which appear white: And theſe Bodies ſeen through Priſms, at the Extremities are tinged with Colours,
* 3574. which does not happen in an homogeneous Colour; * alſo a Circle of white Paper of half an Inch Diameter, being put upon black Cloth, if it is enlightened by theſe Rays, it will appear ob-
* 3501. long through the Priſm *: And the ſame Colours, which are obſerved in the Rays of the Sun, are ſeen here in the ſame Manner; all which Things would not happen, if the Air, as many think, was a blue Liquid; that is, through which only the Sun's blue Rays, at leaſt moſtly ſuch, paſs.

3768. *When we look at the black Sky, the white Rays*, beforementioned, *enter our Eyes, whence the blue Colour of the Sky ariſes.* Becauſe we are accuſtomed to ſee a Colour where there is a coloured Ob-
3769. ject, we alſo refer the Colour of the Heavens to an Object; but ſince this is ſeen equally towards all Parts, *we conceive a concave ſpherical or rather ſpheroidial Surface, in whoſe Center we are placed; we imagine this Surface to be opaque, and therefore diſtant from us beyond all viſible Bodies.*

3770. When a Body is between a Plane and the Eye, of whoſe Diſtance we cannot judge, the Body appears to us to be applied to the Plane, whatſoever the Diſtance is between that and the Plane; for there is no Reaſon why the Parts of the Plane, which are
* 3076. painted at the Sides of the Image of the Body in the Eye *, ſhould not appear at the ſame Diſtance with the Body.

3771. Thence alſo *all the celeſtial Bodies* (of which the leaſt diſtant from us, *(viz.)* the Moon) is yet ſo removed that we can give
* 3116. no Judgment of it's Diſtance *, *are referred to that imaginary*

Sphere

Sphere above-mentioned; *and they all appear equally diſtant, and ſeem to move in the Surface of a concave Sphere.* So the Moon appears to be amongſt the fixed Stars, although it's Diſtance bears ſcarcely any ſenſible Proportion to the Diſtance of *Saturn*, and the Diſtance even of *Saturn* itſelf is nothing compared with the immenſe Diſtance of the fixed Stars. It is no Wonder therefore, that the common People know nothing of the Magnitude of the celeſtial Bodies, and the Immenſity of the Heavens.

We ſee from what has been ſaid how the Motion of any Body being given, and the Motion of the Earth being known, the apparent Motion may be determined. 3772.

We have ſaid that a Sphere is imagined beyond the fixed Stars, in whoſe Center is the Spectator *. The Orbit of the Earth is ſo ſmall, in Reſpect of the Diameter of this Sphere, that the Center of the Sphere is not ſenſibly changed by the Alteration of the Place of the Spectator, whilſt he is carried along with the Earth. Wherefore *in all the Points of the Earth's Surface, and at any Time, the Inhabitants of the Earth imagine the ſame Sphere to which they refer the heavenly Bodies*; and which hereafter we ſhall call *the Sphere of the fixed Stars.* * 3769. 3773.

Theſe Things being laid down, if *we conceive a Line to be drawn through the Earth and a Body, which, being continued beyond the Body, cuts the aforeſaid Sphere*; *we have a Point*, to which the abovementioned Body is referred, and *which is the apparent Place of that Body.* 3774.

Whilſt the Body, or the Earth, or both, are moved, this Line is moved alſo, and *the apparent Motion is the Line which is deſcribed amongſt the fixed Stars by the Extremity of the Line* abovementioned, *which goes through the Earth and the Body, whoſe apparent Motion is obſerved.* 3775.

Therefore *the ſame Appearances will follow from the Earth's being moved out of it's Place, as if the Body had been moved, and the ſame alſo may be deduced from the Motion of both.* 3776.

But if *the Body and the Earth be ſo moved, that the Line which paſſes through theſe Bodies be carried in a parallel Motion, the Body will ſeem to be at reſt amongſt the fixed Stars*; becauſe in this Caſe the Space, gone through by the End of the Line amongſt the fixed Stars, cannot exceed the Space, gone through by the Earth; but the Line that is equal to the whole Space which the Earth can go through, at ſo great a Diſtance as the fixed Stars, is not ſenſible to us. 3777.

From

3778. *From the Motion of the Earth round it's Axis* there *is* alſo *produced* an *apparent Motion*, which will be eaſily deduced in it's proper Place fromthe Foundation laid down in this Chapter.

That the apparent Motion differs from the real, and is varied by the Motion of the Spectator, is what Sailors every Day obſerve.

CHAP. III.

Of the Phænomena or Appearances of the Sun, from the Motion of the Earth in it's Orbit.

Plate 123. Fig. 1. LET the Sun be at S, and the Earth in it's Orbit at T; and let *r s*, be the Sphere of the fixed Stars; the apparent Place
3779. of the Sun will be at *s* *. *When the Earth is carried in it's Orbit*
* 3774. from T to *t*, *the Sun ſeems to move* in *Conſequentia*, and to run
* 3775. through the Arch *r s* *, which meaſures the Angle *r* S *s* equal to the Angle T S *t*, ſo that the Celerity of the apparent Motion of the Sun, depends upon the Celerity of the angular Motion of the Earth, with Reſpect to the Center of the Sun; which Motion increaſes upon a double Account; on Account of the Diſtance from the Sun being leſſened and the Celerity of the Earth
* 3712. being increaſed: Both which Cauſes always concur *; *wherefore*
3780. *the Inequality of the apparent Motion of the Sun is ſenſible.*
3781. *In a whole Revolution of the Earth, the Sun alſo ſeems to run through a whole Circle.*

Definition 1.

3782. *This apparent Way of the Sun is called the* Ecliptic Line. It is the Section of the Sphere of the fixed Stars with the Plane of
* 3707. the Ecliptic *, ſuppoſed to be continued to this Sphere.
3783. This Way is divided into 12 equal Parts, each of which contains 30 Deg. theſe Parts are called the Signs, and are diſtinguiſhed by theſe Names: *Aries* ♈, *Taurus* ♉, *Gemini* ♊, *Cancer* ♋, *Leo* ♌, *Virgo* ♍, *Libra* ♎, *Scorpius* ♏, *Sagittarius* ♐, *Capricorn* ♑, *Aquarius* ♒, *Piſces* ♓. Whence theſe Parts have their Names, we ſhall explain when we treat of the fixed Stars.

3784. *The Sun is longer in going through the ſix firſt Signs than the ſix laſt, and the Difference is nine Days.*

3785. Although a Circle has neither Beginning nor End, yet when ſeveral Points muſt be determined in it, ſome Point muſt be taken

taken *as the Beginning*; this, *in the Ecliptic Line, is the firſt Point of Aries*; we ſhall ſhew how it may be determined hereafter. It is not fixed to one Place amongſt the fixed Stars: Therefore *the Orbits of the Planets*, which alter ſo little, that they may be looked upon as unchangeable *, *don't preſerve the ſame Situation, in Reſpect of this Point.* 3786. * 3696.

DEFINITION 2.

The Diſtance of the Sun from the firſt Point of Aries *meaſured* in conſequentia, *is called* the Sun's Longitude. 3787.

The Longitudes of the other heavenly Bodies are meaſured after the ſame Manner in the Ecliptic; they are referred to that Line, by conceiving a great Circle to paſs through the Body, and cut the Ecliptic perpendicularly; for the Point in which the Ecliptic is cut by this Circle, determines the Longitude of the Body. 3788.

DEFINITION 3.

The Diſtance of a heavenly Body from the Ecliptic is called it's Latitude. It is meaſured by an Arc of a great Circle, perpendicular to the Ecliptic intercepted between the Body and the Ecliptic. 3789.

DEFINITION 4.

If we imagine a Line to go through the Center of the Sphere of the fixed Stars, and perpendicular to the Ecliptic, the Points, in which this cuts the abovementioned Sphere, are called the Poles of the Ecliptic. 3790.

DEFINITION 5.

The Zodiac *is a Zone which is imagined in the Heavens, which the Ecliptic Line cuts into two equal Parts, and which, on either Side, is terminated by a Circle parallel to the Ecliptic Line, and eight Degrees diſtant from it.* On Account of the ſmall Inclinations of the Orbits of the Planets, and the Moon to the Plane of the Ecliptic, *no Bodies of the Planetary Syſtem ever appear without the Zodiac.* 3791. 3792.

DEFINITION. 6.

Thoſe of them that have the ſame Longitude are ſaid to be, in Conjunction. 3793.

DEFINITION 7.

3794. *Thoſe whoſe Longitudes differ* 180 *Degrees, are ſaid to be in Oppoſition.*

CHAP. IV.

Of the Phænomena of the inferior Planets, ariſing from the Earth's and their own Motions in their Orbits.

Plate 123. Fig. 2. LET S be the Sun, A V B *v* the Orbit of an inferior Planet; let T be the Earth in it's Orbit; and *a* v *b* Part of the Sphere
3795. of the fixed Stars; the apparent Place of the Sun v *.
* 3774. If from the Earth there be drawn to the Orbit of the Planet
3796. the Tangents T A *a*, T B *b*, it is evident, that the Planet in it's apparent Motion, is never removed farther from the Sun, than the diſtance v *a*, v *b*; and that the Planet, as it were, accompanies it in it's apparent Motion round the Earth.

DEFINITION 1.

3797. *The apparent Diſtance of the Planet from the Sun is called it's*
3798. Elongation; *v a* or *v b* is *the greateſt Elongation:* This *varies* upon two Accounts; *(viz.)* becauſe the Earth and the Planet both
* 3696. revolve in eliptic Lines *.
3799. *The Planet* performs it's Revolution ſooner than the Earth *;
* 3545. therefore, *in it's Motion*, it *paſſes between the Earth and the Sun, and then moves beyond the Sun, in Reſpect of the Earth: So that it is in Conjunction with the Sun in two Manners*, but *never in Oppoſition.*
3800. That we may have an Idea of the apparent Motion of the Planet, we muſt conceive the Lines T B *b*, T S v, T A *a*, to move along with the Earth; ſo that the Points A, V, B, and *v*, whilſt the Earth performs it's Revolution, may run through the Orbit of the Planet; but the Planet which moves ſwifter, paſſes ſucceſſively through theſe Points over and over.
3801. *When* it is carried in it's Orbit from V to D, it ſeems to move amongſt fixed Stars from v to *d:* In this Caſe, *the apparent Motion is in Antecedentia*, and *the Planet is retrograde.* In D it is
3802. ſaid to be *ſtationary* becauſe *it appears, for ſome Time, in the ſame*
3803. *Place amongſt the fixed Stars.*

This obtains, when the Orbit of the Planet, in the Place in which

which the Planet is, is ſo inclin'd to the Orbit of the Earth, in the place in which the Earth is, that if the Line *t d* be drawn parallel to the Line T D, and at a ſmall Diſtance from it, D *d* be to T *t* as the Celerity of the Planet in it's Orbit, to the Celerity of the Earth; theſe Lines are run through in the ſame Time *; and the Line, which is drawn through the Earth and the Planet, is carried in a parallel Motion; for which Reaſon the apparent Place of the Planet is not changed*. * 119. * 3777

Between *d* and B, the Orbit of the Planet is more inclined to the Orbit of the Earth: wherefore the Extremity of the Line paſſing through the Earth and the Planet (although the Planet moves ſwifter than the Earth) is carried *in Conſequentia*; *towards which* Part alſo *the apparent Motion of the Planet is directed**. Yet ſince the apparent Motion of the Sun exceeds the apparent Motion of the Planet, the Elongation is increaſed, which becomes greateſt, when the Planet is at B. Whilſt the Planet goes through the Arc B *v*, it's apparent Motion is alſo *in Conſequentia*, and exceeds the apparent Motion of the Sun to which it is coming, and then goes beyond it, receding from it, till it comes to A. Between A and E the Motion *in conſequentia* is continued; but the Sun, whoſe apparent Motion in this Caſe is ſwifter, as has been explained concerning the Arc *d* B, comes towards *the Planet*, and the Elongation is diminiſhed. At E, in the ſame Manner as at D, *the Planet is* ſtationary, between E and V it is again retrograde. 3804. 3805. * 3775. 3806.

The Orbit of the Planet is inclined to the Plane of the Ecliptic *; therefore it *does not ſeem to move in the Ecliptic Line, but* ſometimes leſs, ſometimes more diſtant from it, and *appears to be carried in an irregular Curve, which ſometimes cuts the Ecliptic.* * 3706. 3708.

Let N V N be the Orbit of the Planet, whoſe Nodes are N N; let S be the Sun; T *t* the Orbit of the Earth in the Plane Ecliptic; the Earth T; the Planet V. If V A be imagined to paſs through the Planet, and to be perpendicular to the Plane of the Ecliptic, the Angle V T A, or rather the Arc which meaſures it, is the *Latitude* of the Planet *: This is called *the Geocentric Latitude*, to diſtinguiſh it from the Latitude of the Planet ſeen from the Sun, which is called *the heliocentric Latitude*, and is in that Caſe the Angle V S A; here we ſpeak of the *Geocentric Latitude*, becauſe we examine the Phænomena as they appear from the Earth. 3807. Pl. 123. Fig. 3. * 3789.

When a Planet is in the Node, it appears in the Ecliptic Line; and the Curve, which is deſcribed by the Planet, by it's apparent Motion in the Zodiac, cuts the Ecliptic Line; *as the Planet recedes* 3808.

3809. *from the Node, it's Latitude is increaſed, which is alſo different, according to the Situation of the Earth*; ſo the Planet remaining at V, the Latitude is greater if the Earth be at T, than if it was at *t*. Now, if the Earth remaining in it's Place T, we imagine the Planet to be be carried from V to *v*; the Angle *v* T B will be leſs than the Angle V T A upon a double Account, from the Planet coming nearer the Node, and the Spectator being moved farther off.

3810. Now, if we conſider that both the Earth and the Planet are continually moved, we ſhall eaſily conceive that the Latitude is changed every Moment from each Cauſe, which ſometimes act contrariwiſe, and ſometimes conſpire in increaſing and diminiſhing the Latitude; whence it neceſſarily follows, that the apparent Motion is performed in an irregular Curve, which, as was ſaid before, cuts the Ecliptic as often as the Planet paſſes the Node, that is, twice in each of it's Revolutions; this Curve alſo does not recede from the Ecliptic, on either Side, beyond certain Limits in the Zodiac.

3811. We diſcover alſo ſome remarkable Phænomena of the inferior Planets by means of the Teleſcope, which are owing to their Opacity.

Plate 123. Fig. 4.

Let S be the Sun, T the Earth, A, B, C, v, D, E, F, V, an inferior Planet, *ex. gr. Venus* in it's Orbit. This Planet ſhines with Light borrowed from the Sun, and that Hemiſphere only which is turned to the Sun is enlightened, the other Hemiſphere is inviſible: Therefore that Part only of the enlightened Hemiſphere, which is turned to the Earth, can be ſeen from it; in V the Planet cannot be ſeen; it would appear round at v, if the Sun's Rays did not hinder it from being ſeen.

3812. Going from *v* the *Planet continually decreaſes*; at D it has the Figure *d*; at *e* and *f* it is drawn as it appears at E and F, and continues to decreaſe, *till it vaniſhes at* V, *and then again encreaſes ſucceſſively, changing it's Figure*, 'till the whole enlightened Hemiſphere be turned towards the Earth.

3813. *When* the Node is at V, or near it, *the Planet appears in the very Diſk of the Sun*, and as it were applied to *it*, and *is obſerved as a black Spot which moves on the Sun's Surface*; in this Caſe, properly ſpeaking, we don't ſee the Planet, but we perceive where it intercepts the Sun's Rays.

3814. *The leſs diſtant the Planet is from the Earth, the greater it ap-*
* 3151. *pears* *, and the more lucid; but as it comes nearer the Earth, the lucid Part that is viſible is leſs, ſo that on one Account the

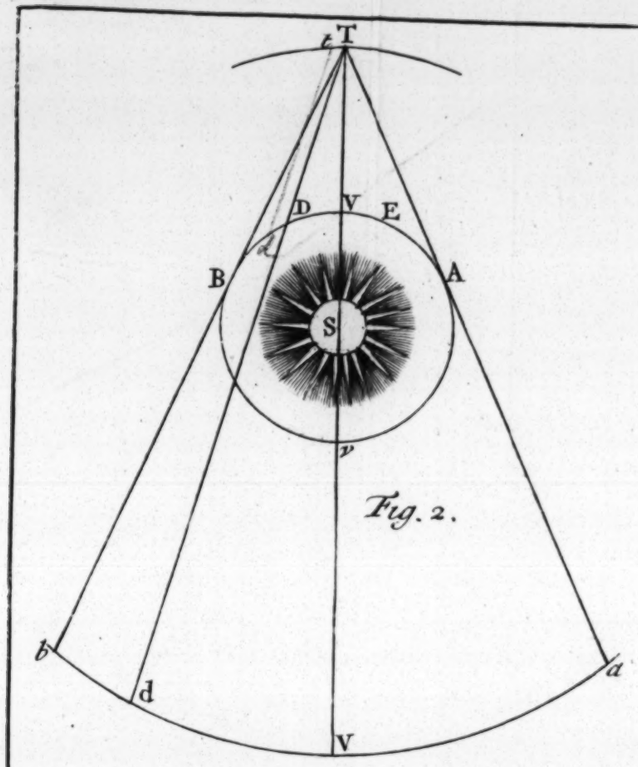


Fig. 2.

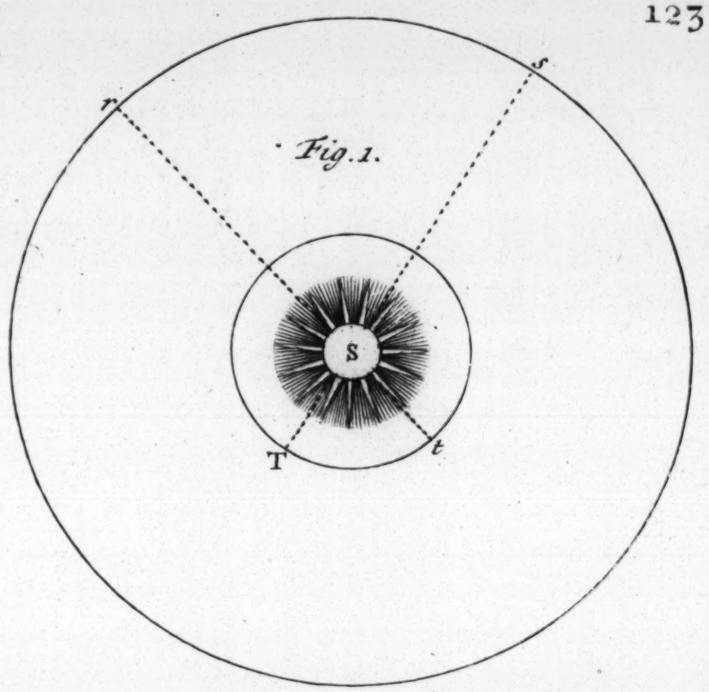


Fig. 1.

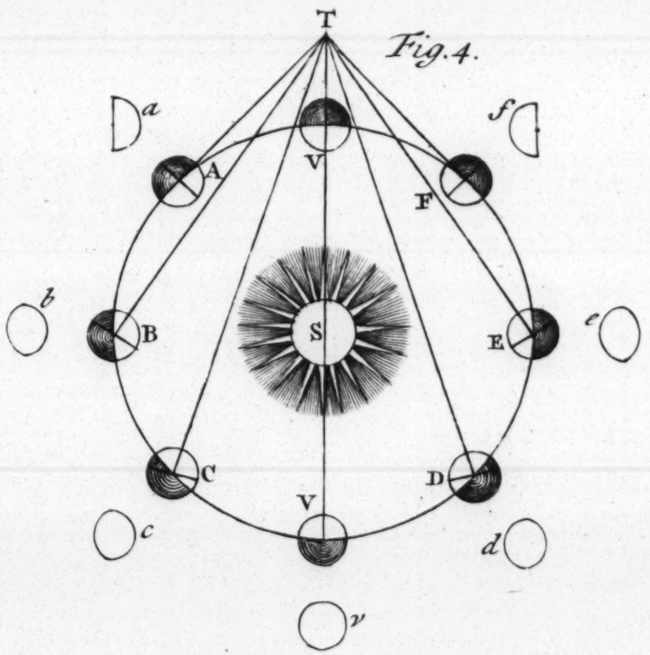


Fig. 4.

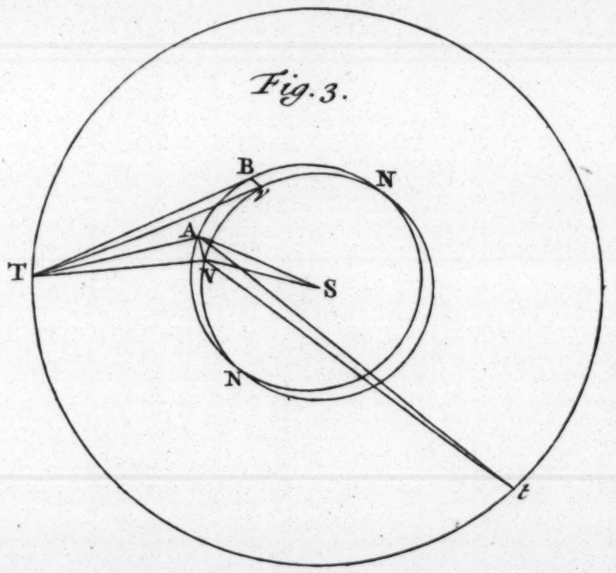


Fig. 3.

Light increaſes, and on another it is diminiſhed; *and there is a Diſtance at which the reflected Light is greateſt.*

CHAP. V.

Concerning the Phænomena of the ſuperior Planets, ariſing from their Motions, and the Motion of the Earth in their reſpective Orbits.

THE apparent Motions of the ſuperior Planets do in many Things agree with what has been explained in reſpect of the inferior Planets, and in many Things diſagree. 3815.

They do not always accompany the Sun, but are often obſerved in Oppoſition; (as has been ſaid of the inferior Planets) *they do not always ſeem to be carried in* Conſequentia, *but often appear ſtationary and often retrograde.* 3816. 3817.

Let M be a ſuperior Planet, for Example, *Mars* in it's Orbit, ATHBC the Orbit of the Earth. The periodical Time of the Earth is ſhorter than the periodical Time of *Mars**; therefore the Earth in it's Motion goes between it and the Sun; in which Caſe, the Planet appears at F, amongſt the fixed Stars oppoſite to the Sun. Through M draw the Lines B M, A M, that touch the Earth's Orbit, which, being continued, go to G and D in the Sphere of the fixed Stars. Let us imagine that whilſt the Planet is carried about in it's Orbit, thoſe Lines are alſo moved; ſo that the Points A and B, in which the Lines that go through the Planet touch the Orbit of the Earth, perform a Revolution in the periodical Time of the Planet. Now ſince the Earth revolves faſter, it paſſes through the Points A and B in it's Motion. In this Motion the apparent Place of the Planet, ſeen from the Earth, is not removed from the Place of the Planet ſeen from the Sun beyond F D and F G. Let T be ſuch a Point in the Orbit of the Earth, that the Line *t m*, being drawn, may be parallel to T M; Let T *t* be to M *m*, as the Celerity of the Earth to the Celerity of the Planet; in which Caſe theſe ſmall Lines are gone through in the ſame Time *; in the mean Time the Planet ſeems to be at reſt*, and is ſaid to be ſtationary. In the ſame Manner it is ſtationary when the Earth is at H. In the Motion of the Earth between T and H, the Planet appears to move in *Antecedentia* from E through

3818. Plate 124, Fig. 1.

* 3717.

* 119.

* 3777.

through F to I, and is ſaid to be retrograde; whilſt the Earth goes through the reſt of it's Orbit HBCAT the Planet is direct.

3819. *The Phænomena, which relate to the Latitude, are like thoſe which*
* 3806. *have been explained, in reſpect to the inferior Planets* *.

3820. *Jupiter and Saturn* encompaſs the Orbit of the Earth at a great Diſtance; wherefore almoſt their whole Hemiſpheres, which are enlightened by the Sun, are viſible from the Earth; and therefore theſe Planets *always appear round.*

3821. Becauſe *Mars* is leſs diſtant, it *appears a little gibbous, between the Conjunction and Oppoſition with the Sun.*

CHAP. VI.

Concerning the Phænomena of the Satellites, from their Motion in their Orbits. Where we ſhall ſpeak of the Eclipſes of the Sun and Moon.

3822. THE *Satellites of Jupiter and Saturn do always accompany their Primaries in their Motion*, and *never appear to recede from them beyond certain Limits on either Side*, which may be eaſily determined from their Diſtances from their Primaries; *and they are alternately carried in Antecedentia* and in *Conſequentia*. Sometimes all of them are on the ſame Side of the primary Planet, and ſome-
3823. times the Primary is obſerved to be between them; *Jupiter's Satellites are all always in the ſame Right Line, or very little diſtant from it.* All which Things may be deduced from this, that the Motion about the primary Planets is performed in Planes that make ſmall Angles with one another, and with the Plane of the Ecliptic.

3824. All theſe *Satellites* of Saturn or Jupiter are not always viſible at the ſame Time, *when they are between their Primary and the Earth, they cannot be diſtinguiſhed from their Primary: Sometimes they are hid by their Primary*, and *often immerſed in it's Shadow.*

DEFINITION I.

3825. *Such an Immerſion in the Shadow is called an Eclipſe of the Sa-*
Plate 85. *tellite.*
Fig. 1. We have treated of this before *. Whilſt the Secondary moves
* 2624. from E to F it undergoes an Eclipſe; and, not being enlightened
2625. by the Sun, becomes inviſible. If we conſider the two firſt Satellites of Jupiter, only the Immerſion into the Shadow at E is viſible,

ſible, when the Earth is in the Part C D A of it's Orbit. On the contrary, the Emerſion only can be ſeen if the Earth be in the Part A B C.

Amongſt the Bodies that accompany *Saturn*, we have ſaid that there is a *Ring* *; concerning which it is to be obſerved, that an Obſerver upon the Earth *never ſees it wider than Saturn's Diameter, and that ſometimes it is inviſible*; namely, when the Plane of the Ring being continued, goes through the Earth; for the Thickneſs of the Ring is not ſenſible. 3827. * 3732.

The Ring is alſo inviſible, when it's Plane continued, paſſes between the Earth and the Sun; for then the enlightened Surface of the Ring is turned from the Earth. 3828.

In each caſe *Saturn* appears round, yet in the laſt Caſe, by reaſon of the Rays that are intercepted by the Ring, there appears a black Belt upon the Surface of the Planet, like that which is occaſioned by the Shadow of the Ring. 3829.

The Phænomena of the Earth's Satellite, namely, of the Moon, are very remarkable in reſpect to us, and therefore particularly to be explained. 3830.

It is very often in Conjunction with the Sun, and as often in Oppoſition to it, but not at every Revolution of the Moon in it's Orbit; for whilſt the Moon, after one entire Revolution of 27 Days, and 7 Hours, returns again to the Place, amongſt the fixed Stars, in which it was in Conjunction with the Sun, the Sun is gone from that Place, and is about 27 Deg. diſtant from it *: therefore it does not reach the Sun till after ſome Days; *the neighbouring Conjunctions are twenty nine Days and a half diſtant from one another.* 3831. * 3729. 3781. 3832.

Definition 2.

The Lunar periodical Month is the Time of one Revolution of the Moon in it's Orbit. 3833.

Definition 3.

The Moon's ſynodical Month, or a Lunation, is the Time that the Moon ſpends between the two next Conjunctions with the Sun. 3834.

The Moon is inviſible in it's Conjunction with the Sun, becauſe the enlightened Hemiſphere is turned from the Earth. Let T (*Plate* 124. *Fig.* 2.) be the Earth, N the Moon between the Sun and the Earth, the enlightened Hemiſphere will be *m l i*, which cannot be ſeen from the Earth. 3835.

Whilſt

3836. *Whilſt the Moon is carried* in it's Orbit, *from the Conjunction to the Oppoſition*, the enlightened Part, which is directed towards the Sun, *does continually become more and more viſible to the Inhabitants of the Earth*; and in the Points A, B, C, the Moon does ſucceſſively acquire the Figures *a b c*.

3837. At P, in it's *Oppoſition with the Sun, it appears round*; *then going through* D, E, F, *it decreaſes* as it is repreſented at *d*, *e*, *f*.

Definition 4.

3838. *The Conjunction of the Moon with the Sun is called the new Moon.* After the Conjunction, the Moon is as it were renewed.

Definition 5.

3839. *The Oppoſition of the Moon with the Sun is called the full Moon, becauſe the whole Moon appears enlightened.*

Definition 6.

3840. *The Conjunction and Oppoſition of a Satellite with the Sun, are called by the common Name* Syzygies.

3841. At A and F, the dark part of the Moon is a little enlightened by the Rays that are reflected from the Earth; and therefore it is ſeen by a Spectator to whom the Sun is not viſible, that is, in the firſt Caſe, after the ſetting of the Sun, and in the ſecond, before it's riſe.

Definition 7.

3842. *When the Light of the Sun is intercepted by the Moon, ſo that, in reſpect of any Obſerver upon the Earth, the Sun is partly or wholly covered, the Sun is ſaid to undergo an* Eclipſe.

3843. Properly ſpeaking, this is an Eclipſe of the Earth, on whoſe Surface the Shadow or Renumbra of the Moon falls.

Definition 8.

3844. *An Eclipſe of the Moon is the Obſcuration of the Moon by the Shadow of the Earth.*

3845. *The Eclipſe of the Sun is never obſerved except at the Time of the New Moon.*

3846. *The Moon is never eclipſed but at the Time of the full Moon.*

3847. *Yet the Luminaries are not eclipſed at every one of the Syzygies,*
* 3742. becauſe the Moon does not move in the Plane of the Ecliptic *, in which the Sun and Earth always are; wherefore upon Account of

Account of the Moon's Latitude, it's Shadow, at the new Moon, often does not touch the Earth; and itſelf, at the full Moon, paſſes beſide the Shadow of the Earth.

But *when the Moon* has no Latitude, or but very little, that is, when it *is in the Node, or near it, at it's Syzygies, an Eclipſe is obſerved*; in that Caſe the Moon appears to be in the Ecliptic, or very near it; and this it is that has given the Name to that Line. 3848.

That what relates to the Eclipſe of the Moon may appear the more plainly, let O O be the Way of the Moon, R R the Plane of the Ecliptic; the Center of the Earth's Shadow is always in it *; N is the Node of the Moon's Orbit. 3849. Pl. 125. Fig. 1. * 3707.3709.

If the Earth's Shadow be at A, the Moon that goes by at F will not be darkened. 3850.

If the Moon be the leſs diſtant from the Node at the full Moon, as at G, the Shadow of the Earth is at B, and *the Moon is darkened in Part*; *this is called a partial Eclipſe.* 3851.

If ſuppoſing the Shadow at D, the Moon be full, *the Moon* will *be wholly darkened* at I, it runs into the Shadow at L, and goes out of it at H; and *the Eclipſe is ſaid to be total.* 3852.

The Eclipſe is ſaid to be central, when the Center of the Moon goes through the Center of the Shadow, which only happens in the very Node N. 3853.

We have hitherto ſpoken of the Shadow of the Earth; becauſe, when we mention the Earth, we underſtand it's Atmoſphere which is joined to it, of which we have ſpoken elſewhere *: *The Shadow of the Atmoſphere is* properly *conſidered in lunar Eclipſes*; for the Shadow of the Earth itſelf does not reach the Moon. 3854. * 2080.

Let T be the Earth, the Atmoſphere about it F D G G D F. The Sun's Rays B D, B D, touching the Atmoſphere; theſe go ſtreight on, and terminate the Shadow of the Atmoſphere, out of which if the Moon be, it is immediately enlightened by the Sun's Rays; but it is not enlightened in the ſame Manner all the while it is between B D and B D. 3855. Plate 124. Fig. 3.

The Rays which enter the Atmoſphere obliquely are refracted*; and as they come towards the Earth, they continually penetrate into a Medium which is denſer and denſer †, and therefore are every Moment inflected*, and *move in Curves.* So the Rays E F, E F, penetrate the Atmoſphere in the Curves F G, F G, that touch the Earth. All the Light between E F, E F, is intercepted by the Earth, and the Rays G A, G A, terminate the Earth's Shadow. 3856. * 2778. † 2110. * 2787.2829.

3857. The Light between EF and BD, being refracted by the Atmoſphere, is ſcattered between G A and B D continued, and beyond A the Point of the Earth's Shadow, the Lights that come from all Parts are confounded, but are continually weaker and weaker the far-
3858. ther from the Earth : So that *the Shadow of the Atmoſphere is* not a perfect Shadow *but a weak Light* whereby the Moon is viſible in an Eclipſe.

3859. *The Shadow of the Atmoſphere* is conical, becauſe the Sun's Diameter is greater than the Diameter of the Atmoſphere, which is ſcarce bigger than that of the Earth ; and this Cone *to Mars*, as appears from immediate Obſervations ; but the Shadow of the Diameter, in the Place where it is cut by the Moon's Orbit, is ſcarce one fourth leſs than the Diameter of the Earth.

With the ſame Reaſoning that we have proved, that the Moon
3860. comes into the Shadow of the Atmoſphere, when the Moon in it's full is in the Node or near it ; it is alſo proved, that the Moon's Shadow falls upon the Earth *at the new Moon, when the Moon is*
3861. *in the Node, or near the Node* ; therefore in that caſe *the Sun undergoes an Eclipſe* ; concerning which, ſeveral Things are to be obſerved.

Let S be the Sun, L the Moon ; let the Shadow of it fall up-
3862. on any Plane G H. This Shadow is encompaſſed with a Penum-
Pl. 124. bra, for beyond M and E that Plane is enlightened by one entire
Fig. 4. Hemiſphere of the Sun ; as you go from M to H, and from E to G, the Light is continually diminiſhed, and near G and H the Rays come to the Plane only from a ſmall Part of the Sun's Surface.

Definition 9.

This diminiſhed Light, which encompaſſes the Shadow G H *every*
3863. *Way, is called the* Penumbra.

In the Eclipſe of the Moon, the Shadow of the Earth is encom-
3864. paſſed with *the like Penumbra*, but this is only ſenſible near the Shadow, and therefore *has but a ſmall Breadth* ; *but* if *an Obſerver*
3865. be placed upon a Plane upon which the Shadow falls, he *may obſerve the whole Penumbra* ; as is the Caſe *in the Eclipſe of the Sun.* An Obſerver I or F can only ſee the Semi-diameter of the Sun, the reſt of the Diameter is hid by the Moon ; and going from M towards H, the Sun is continually more and more hid by the Moon, till it becomes wholly inviſible in the Shadow itſelf.

Hence it follows, *that there is a ſolar Eclipſe, though the Shadow of the Moon does not touch the Earth, provided the Penumbra comes to it's Surface.* And alſo, *that the Eclipſe is not obſerved in all the Places in which the Sun is viſible; and that it is different,* according as the Shadow, or a different Part of the Penumbra goes through the Place, *in the Places in which it is obſerved.* 3866. 3867. 3868.

But the Eclipſe of the Moon is every where the ſame, where the Moon is viſible, during the Eclipſe. 3869.

But when the Shadow itſelf of the Moon falls upon the Earth, the Sun's Eclipſe is ſaid to be total; if only the Penumbra reaches the Earth, it is ſaid to be partial; and this is what happens when we conſider an Eclipſe in general. 3870.

But as to particular Places, *it is ſaid to be total in thoſe Places where the Shadow paſſes; central, in thoſe* where the Center of the Shadow paſſes, that is, *where the Center of the Moon covers the Sun's Center;* and laſtly, *partial, where the Penumbra only goes by;* and this is drawn in *Fig.* 5. 3871.

The wider the Shadow G H *is, the more Places is the Eclipſe of the Sun Total in, and the longer is the Sun wholly obſcured.* But the Breadth of the Shadow is different according to the different Diſtances of the Moon from the Earth, and of the Earth from the Sun. 3872. Plate 124. Fig. 4.

If there be an Eclipſe of the Sun, ſuppoſing the Earth in the Perihelion and the Moon in the Apogæum, that is, at the greateſt Diſtance from the Earth, the Shadow of the Moon does not reach the Earth, and *the Moon does not cover the whole Sun; ſuch an one is called an annular Eclipſe,* and is repreſented in *Fig.* 6. 3873.

CHAP. VII.

Of the Phænomena ariſing from the Motion of the Sun, the Planets, and the Moon about their Axes.

THE *Sun's Motion about it's Axis is ſenſible, by obſerving the Spots,* which are ſeen very often upon the Sun's Surface: Theſe Spots ſeem to change their Figure and Situation every Day, and ſometimes to move ſwifter, ſometimes ſlower; all which Things may be eaſily deduced from the Motion of the ſpherical Surface; and the Sun, which if it was not moved by ſuch a Motion, would only once in a Year ſucceſſively turn it's whole Surface 3874.

to the Earth, now ſhews it to the Inhabitants of the Earth in leſs than the Space of one Month.

3875. Such like Phænomena ariſe from *the Rotations of Jupiter, Mars and Venus, about their Axis,* which Motions *become ſenſible, by obſerving the Spots in the Surface of the Planets.*

3876. Whilſt the Earth is moved round it's Axis, the Obſerver, who is carried round, imagines himſelf to be at reſt, and all the heavenly Bodies to be in Motion.

Definition 1.

3877. *The Points, in which the Axis of the Earth, being continued both Ways, touches the Sphere of the fixed Stars, are called the* Poles of the World.

Definition 2.

3878. *The apparent Motion, ariſing from the Motion of the Earth about it's Axis, is called* the Diurnal Motion.

Definition 3.

3879. *A Plane is conceived to paſs through the Center of the Earth, perpendicular to it's Axis, and continued every Way, and the Circle in which it cuts the Sphere of the fixed Stars is called* the cœleſtial Æquator.

3880. *In the Motion of the Earth, round the Sun,* the Æquator is moved;
* 3721. but ſince the Plane of this Circle is carried by a parallel Motion *,
† 3777. *the cœleſtial Æquator is not moved* †.

Definition 4.

3881. *Circles whoſe Planes go through the Axis of the Earth, are called* Meridians.

3882. *They all paſs through the Poles of the World, and are perpendicular to the Æquator.*

Definition 5.

3883. 3884. *The Arch of any Meridian, which is intercepted between the Æquator and a Star, is called* the Declination of that Star.

Plate 125. Fig. 2. Let an Obſerver be upon the Earth T, who directs his Sight along T A; after a little Time, when the Line T A ſhall be carried by the Motion of the Earth to T *a*, if the Spectator directs his Sight along the ſame Line, the Body A will appear to have been carried through the Arch *a* A; but when the Line has returned to it's former Situation T A, the Body will ſeem to have per-

performed one whole Revolution. But if he directs his Sight along the Axis of the Earth produced, becauſe that's at reſt, the Body, which is ſeen in the Axis, will appear not to have moved; *therefore in the Poles of the World the diurnal Motion is not obſerved* *. But that Bodies, which are near the Poles, are moved round them is plain; and that the Body by it's diurnal Motion deſcribes ſo much a greater Circle round the immoveable Pole, as it is farther diſtant from it. Therefore *the whole Sphere of the fixed Stars ſeems to revolve about the Axis of the Earth continued* in Antecedentia, *in that Time in which the Earth really turns about it's Axis.* Therefore the diurnal Motion is common to all the cœleſtial Bodies, except ſo far as it is diſturbed by the Motions abovementioned. 3885. * 3877. 3886.

The Æquator is equally diſtant from both Poles, and divides the Heavens into two Hemiſpheres, whoſe middle Points are the Poles of the World, which therefore are equally diſtant from the ſeveral Points of the Æquator; therefore *the heavenly Bodies which are in the Æquator by their diurnal Motion ſeem to deſcribe the Æquator* itſelf, the greateſt Circle of all that can be deſcribed by the diurnal Motion; *the other Bodies deſcribe Circles parallel to the Æquator.* 3887. 3888.

The Axis of the Earth is inclined to the Plane of the Ecliptic in an Angle of 66 Deg. 31 Min. * *the Poles of the World* therefore *are diſtant from the Poles of the Ecliptic* 23 Deg. 29 Min. *and the Plane of the Æquator makes an Angle with the Plane of the Ecliptic* of 23 Deg. 29 Min. Both Planes paſs through the Center of the Earth, but ſince this may be looked upon as the Center of the Sphere of the fixed Stars*, it follows, that *the Æquator and the Ecliptic Line are great Circles, which* are inclined to each other, and *cut one another in two oppoſite Points in the Beginning of* Aries, *and the Beginning of* Libra, which Points in the Way of the Sun, are determined by theſe Interſections *. * 3729. 3889. *3769. 3773. 3890. *3783. 3888.

When the Sun is in thoſe Points it ſeems to deſcribe the Æquator by it's diurnal Motion *; *when it is carried* about *in the Ecliptic* by it's apparent Motion, it continually recedes more and more from the Æquator, and it's Declination is increaſed, and *it deſcribes leſs Circles every Day* *; *till it comes to it's greateſt Diſtance from the Æquator, which is* 23 Deg. 29 Min. † *then it comes back to the Æquator again, and goes beyond it alſo* 23 Deg. 29 Min. *advancing towards the oppoſite Pole.* 3891. 3892. * 3888. † 3889. 3893.

DEFI-

DEFINITION 6.

3894. *Thoſe Circles, deſcribed by the Sun in it's diurnal Motion, which are moſt diſtant from the Æquator, that is* 23 Deg. 29 Min. *are called* the Tropics.

3895. One touches the Ecliptic Line in the firſt Degree of *Cancer*, and is called the *Tropic of Cancer*; the other is called the *Tropic of Capricorn*, and paſſes through the firſt Point of the Sign *Capricorn* and there touches the Ecliptic Line.

DEFINITION 7.

3896. *The Pole of the World, which is next to the Tropic of Cancer, is called the* Arctic Pole, *and alſo the* North Pole; *the Oppoſite is called* the Antarctic, *and alſo* the South Pole.

DEFINITION 8.

3897. *The Circles* that are deſcribed in the diurnal Motion by the Poles of the Ecliptic, that is, by the Points *which are diſtant from the Poles of the World* 23 Deg. 29 Min. *are called* the Polar Circles.

3898. The Arctic Polar Circle is that which ſurrounds the Arctic Pole; the other oppoſite one borrows it's Name from the Antarctic Pole.

There remains to be explained *the Moon's Motion about it's Axis, whoſe Effect is that the ſame Face of the Moon is always turned towards the Earth.*

3900. Pl. 124. Fig. 2. Let the Moon be at N the Face which is turned to the Earth is $m\,n\,i$; if the Moon did not turn about it's Axis, and all it's Points were carried through parallel Lines, the Line $m\,i$ would coincide with the Line $l\,n$ in the Situation of the Moon at B, and the aforeſaid Hemiſphere $m\,n\,i$ would be at $l\,m\,n$; but becauſe, whilſt the Moon deſcribes a fourth Part of it's Orbit, it performs likewiſe $\frac{1}{4}$ of it's Revolution round it's Axis, the Face, which would be at $l\,m\,n$, is now at $m\,n\,i$, that is, again turned to the Earth.

After the ſame Manner it is proved, that this ſame Face $m\,n\,i$, when the Moon is at P, is ſeen by an Obſerver on the Earth, and that it is turned towards the Earth at E; as alſo in all other Points of the Moon's Orbit.

That Part of the Moon's Face which, by it's Motion in it's Orbit, is continually turned from the Earth, is turned again towards it by the Moon's Motion round it's Axis.

But

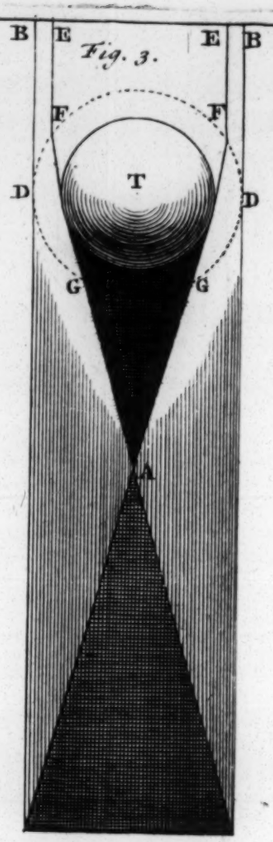


Fig. 3.

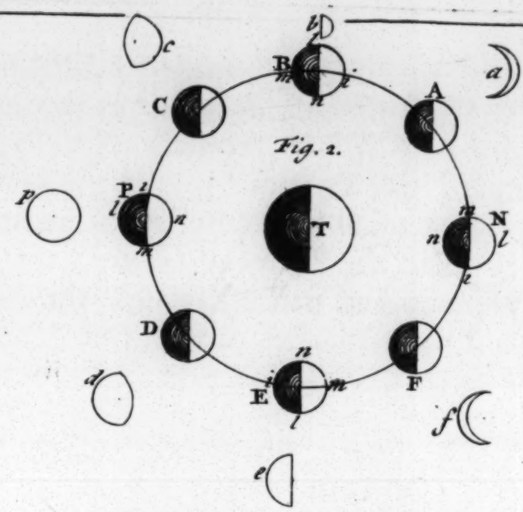


Fig. 2.

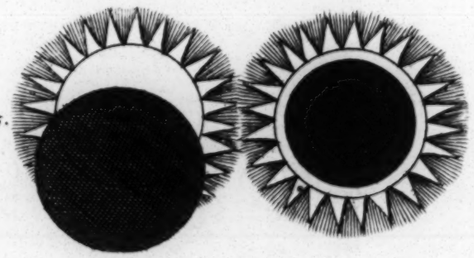


Fig. 5. Fig. 6.

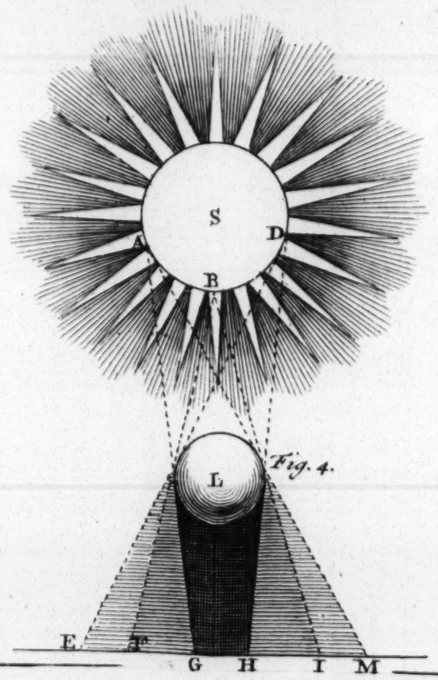


Fig. 4.

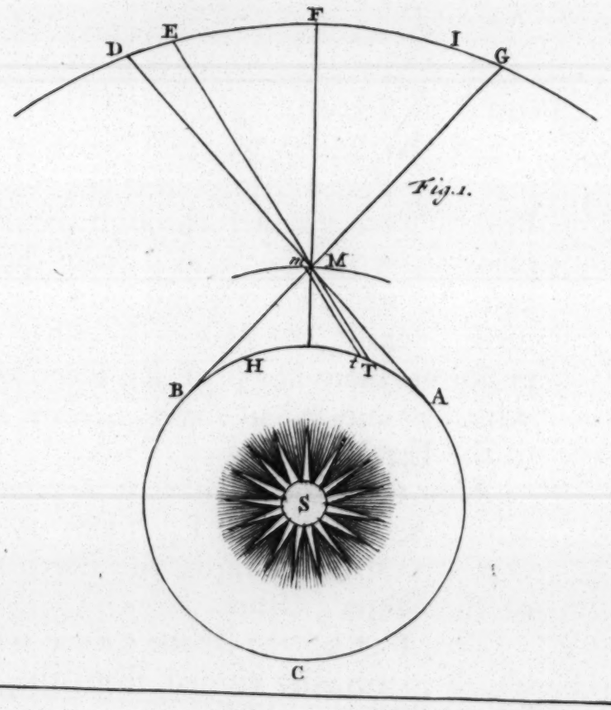


Fig. 1.

But as it's Motion about it's Axis is equal, and it is carried in it's Orbit with an unequal Celerity *; it happens that the Moon being in the Perigæum, that is at the leaſt Diſtance from the Earth, where it is moved very faſt in it's Orbit *, it does not entirely turn back again towards the Earth by it's Motion round it's Axis, that Part of it's Surface, which it turns from it by it's Motion in it's Orbit; therefore a Part of the Surface of the Moon which was not ſeen before, appears at it's Side; which becomes again inviſible, when the Moon comes to it's apogeon. 3091. * 3739. 3740. * 3739.

For that Reaſon *the Moon ſeems to be moved with a libratory Motion.* 3902.

There is alſo another libratory Motion obſerved in the Moon. 3903.

The Axis of the Moon not perpendicular *to the Plane of it's Orbit*, but *a little inclined* to it: The Axis keeps it's Paralleliſm in it's Motion round the Earth, as has been ſaid of the primary Planets *; therefore it changes it's Situation in Reſpect of an Obſerver upon the Earth, to whom ſometimes one, ſometimes the other Pole of the Moon is viſible. 3904. * 3721.

CHAP. VIII.

Of the Phænomena which relate to the Surface of the Earth, and it's particular Parts.

WE have explained the cœleſtial Phænomena hitherto examined, by conſidering the Spectator as carried about by thoſe Motions wherewith the Earth is really moved. Now we ſhall conſider him as placed upon the Surface of the Earth, and carried from one Place to another upon it. 3905.

The firſt Phænomena to be here obſerved is, that, *by Reaſon of the Interpoſition of the Earth, one Half of the Heavens is inviſible to the Obſerver who is placed upon the Surface of the Earth.* 3906.

DEFINITION I.

That Circle in the Heavens, which ſeparates the viſible from the inviſible Part, when the Rays are not intercepted by the Inequalities of the Earth's Surface, *is called the Horizon.* 3907.

When the Height, to which the Spectator can be raiſed above the Surface of the Earth, is very ſmall, compared with the Semidiameter of the Earth; the Eye of the Spectator may be looked upon as placed in the Surface itſelf. 3908.

Let

3909. Let the Earth be at T, and the Obſerver at S, and PE *pe* the
Pl. 125. Sphere of the fixed Stars; if you conceive a Plane at HH to touch
Fig. 4. the Earth and go through S, it will be the Plane of the Horizon,
whoſe Section with the Sphere of the fixed Stars is the Horizon.
A Plane at *h h*, is conceived to go through the Center of the Earth
parallel to HH; the Diſtance *h* H is inſenſible, by reaſon of the
immenſe Diſtance of the fixed Stars; therefore the Section of that Plane,
* 3777. with the Sphere abovementioned, may be taken for the Horizon* HH.

DEFINITION 2.

3910. *The Aſcent of the Stars, above the Horizon, is called their Riſe.*

DEFINITION 3.

3911. *The Deſcent, below the Horizon, is called the ſetting of the Stars.*

DEFINITION 4.

3912. *If we conceive a Line drawn through the Obſerver and the Center of the Earth,* which muſt neceſſarily be perpendicular to the Horizon, *it will reach the Point* Z *among the fixed Stars, which is called the* Zenith.

DEFINITION 5.

3913. *The Point* N, *oppoſite to it the Nadir.*

DEFINITION 6.

3914. *The Section which a Plane of the Meridian*, that goes through*
* 3881. *the Obſerver, makes with the Horizon, is called the* Meridian Line; and is directed from North to South.

DEFINITION 7.

3915. *The Eaſtern Part of the Heavens is that, towards which we ſee the cæleſtial Bodies riſe above the Horizon.*

3916. *The oppoſite Part of the Heavens, in which the ſame Bodies go down below the Horizon, is called the weſtern Part.*

3917. Theſe two Points are ſeparated by a Meridian Line, which we conceive to be continued both Ways, in the Plane of the Horizon, quite up to the Heavens.

3918. *The Eaſt Point is that, in which a Line directed Eaſtwards, perpendicular to the Meridian Line, and going through the Obſerver, cuts the Sphere of the fixed Stars.*

DEFINITION 8.

The Point oppoſite to this is called the Weſt Point. 3919.

DEFINITION 9.

The Amplitude *is an Arch of the Horizon, which is contained between the Eaſt or Weſt Point, and the Point in which the Star riſes or ſets,* the firſt is called the riſing and the other the ſetting Amplitude; and each is either northern or ſouthern Amplitude. 3920.

DEFINITION 10.

The Height or Altitude of a Star, above the Horizon, *is the Arch of a Circle perpendicular to the Horizon, in whoſe Center the Spectator is, terminated by the Horizon and the Star.* 3921.

When Bodies are remote, the Altitude does not ſenſibly differ, whether the Spectator be in the Surface of the Earth, or ſuppoſed at it's Center; Bodies that are leſs diſtant appear higher to a Spectator placed in the Center. 3922.

DEFINITION 11.

The Difference of the Height of a Star, according to the different Poſition of the Obſerver, as he is ſuppoſed in the Center, or on the Surface of the Earth, is called the Parallax of the Star. 3923.

There is only the Parallax of the Moon, which can be determined by Obſervations: The Diſtance of the reſt of the Bodies in the planetary Syſtem is too great to be compared with the Semidiameter of the Earth; and the Parallax depends upon the Ratio which the Semidiameter of the Earth has to the Diſtance of a Planet; therefore even *the Parallax of* Mars, *in Oppoſition with the Sun, is too ſmall for the niceſt Obſervations.* 3924. 3925.

Where there is *a Parallax,* it *diminiſhes as a Body aſcends above the Horizon, and vaniſhes in the Zenith.* 3926.

The apparent Height of the Stars is alſo changed upon another Account, which equally affects all the heavenly Bodies. The Rays are inflected *by the Refraction of the Atmoſphere*, and *the Stars appear higher than they are* * ; *yet the higher they are, the leſs is that Inflexion* †; becauſe the Rays fall leſs obliquely on the Surface of the Atmoſphere. *In the* Zenith *there is no Refraction* * ; *even at the Diſtance of twenty or thirty Degrees from the* Zenith, *it is not ſenſible.* * 3927. 3928. 3929. 3856. † 2809. 3930. * 2793.

Since *the Stars* are raiſed *by the Refraction*, they *are viſible before they come to the Horizon.* 3931.

3932. All theſe Things relate to the Surface of the Earth in general,
Plate 126. now we muſt examine the ſeveral Parts of it; theſe are determin-
Fig. 2. ed by referring to the Earth the Circles which we have before
3933. conſidered in the Heavens; *ſo on the Earth we conſider the Æquator, the Meridians, the Tropics, and Polar Circles*; and theſe Circles divide the Surface of the Earth in the ſame Manner as the Sphere of the fixed Stars is divided by the Circles in the Heavens; and therefore the Circles in the Heavens, and thoſe upon the Earth, do ſo mutually correſpond with each other, that a Line being drawn from the Center of the Earth to a Circle in the Heavens, it will go through the ſame Circle in the Earth. If the Poles are P *p*, the Æquator will be E *e*, the Tropics T T, *t t*, and the Polar Circles A A, *a a*.

DEFINITION. 12.

3934. *The Meridian which goes through a Place is called the* Meridian of the Place.

3935. *The Plane of it is perpendicular to the Horizon*; becauſe it goes through the Center of the Earth and the Obſerver.

3936. *A Meridian Line drawn in any Place, is Part of the Meridian*
* 3914. *of the Place*.*

DEFINITION 13.

3937. The Latitude of a Place *is it's Diſtance from the Æquator*; that is, the Arch of the Meridian intercepted between that Place and the Æquator.

DEFINITION 14.

3938. *Circles parallel to the Æquator, are called* Circles of Latitude as B *b*.

3939. By determining the Latitude of the Place, we determine the Circle of Latitude, which goes through the Place; now to determine the Situation of ſeveral Places, in Reſpect of each other, we muſt determine Places upon the ſeveral Circles, which is done, by ſuppoſing a Meridian to paſs through any remarkable Place, which by it's Section determines a Point upon each Circle of Latitude, from which the Diſtances of Places are meaſured.

DEFINITION 15.

3940. *The Meridian abovementioned, taken at Pleaſure, is called the* firſt Meridian.

DEFI-

DEFINITION 16.

The Diſtance of a Place from the firſt Meridian meaſured on a Circle of Latitude that goes through a Place is called the Longitude of the Place. 3941.

Aſtronomers refer every Thing to the Meridian of the Place in which they make their Obſervations. 3942.

In explaining the Phænomena which relate to the ſeveral Parts of the Surface of the Earth, we ſhall conſider the Obſerver going from the Pole to the Æquator; and firſt only take Notice of the diurnal Motion. 3943.

When the Spectator is at S, in the very Pole of the Earth T, the cœleſtial Æquator E *e* coincides with the Horizon, and the Pole of the World P is the Zenith; in that Caſe, becauſe the Circles, which are parallel to the Horizon, are alſo parallel to the Æquator; all the heavenly Bodies appear to be carried by a Motion parallel to the Horizon *, in Circles which are repreſented by the Lines A *a*, B *b*. *The heavenly Bodies in the Hemiſphere E P e never ſet, and the others are never viſible.* 3944. Plate 125. Fig. 3. * 3888.

The Horizon in this Situation is ſaid to be parallel, or this Situation is called a parallel Sphere. 3945.

If an Obſerver upon the Earth T *recedes from the Pole,* and is at S, *the Horizon is ſaid to be oblique, or the Sphere is oblique*; then the Axis P *p* is inclined to the Horizon *h h*, ſo much the more as the Obſerver is farther from the Pole. 3946. Plate 125. Fig. 4.

DEFINITION 17.

The Angle which the Axis of the Earth makes with the Horizon, is called the Height of the Pole *. 3947. * 3921.

This *Height of the Pole is equal to the Latitude.* The Height of the Pole is the Angle P T *h*, whoſe Meaſure is the Arch P *h*; the Latitude is meaſured by an Arch, which upon the Earth correſponds to the Arch Z E in the Heavens*: But this is equal to the Arch P *h*; for the Complement of each of them, to a Quarter of a Circle, is the Arch Z P. 3948. * 3937.

In this Poſition of the Obſerver, becauſe the Æquator is inclined to the Horizon, *all the heavenly Bodies are carried by the diurnal Motions in Circles inclined to the Horizon,* repreſented by the Lines A *a*, B *h* *. 3949. * 3888.

Some of the heavenly Bodies riſe and ſet at every Revolution of the Earth; namely thoſe which are between the Parallels to the Æ- 3950.

quator B *h*, and *h i*; becauſe all the Parallels between thoſe are cut by the Horizon.

3951. The Planes of the Æquator and the Horizon go through the Center of the Earth; therefore theſe Circles cut one another mutually into two equal Parts, and half of the Æquator is above the

3952. Horizon; therefore *the heavenly Bodies, which are in the Æquator, are above the Horizon during half a Revolution of the Earth about it's*

* 3887. *Axis* *; *and* on Account of the Equability of the Motion about the Axis *are inviſible during an equal Time.*

3953. *Theſe alſo riſe due Eaſt and ſet due Weſt*, (that is, in the very Points of the Eaſt and Weſt;) for the Section of the Planes of the Æquator and the Horizon is perpendicular to a Plane perpendicular to both theſe Planes; and this laſt Plane is the Plane of the Meridian

*3881. of the Place *.

3935. Wherefore the abovementioned Section is perpendicular to the

† 3936. Meridian Line †, and conſequently goes through the Eaſt and Weſt

‡ 3918.3919. Points ‡.

3954. *Bodies between the Æquator and a parallel* B *h*, *which touches the Horizon*, as in the Circle A *a*, *continue longer above than below the Horizon; and this Difference is ſo much the greater, the more the*

3955. *Circle* A *a approaches that Pole, which is above the Horizon.* On the contrary, *as the Body goes towards the oppoſite Pole, it's Time of Continuance above the Horizon is the longer.*

3956. *This Inequality of the Time, that a Body is above and below the Horizon encreaſes as the Height of the Pole does*, becauſe of the Diminution of the Angle made with the Horizon by the Æquator and it's Parallels.

3957. *Bodies, whoſe Diſtance from the Pole is equal to the Height of it, never ſet*, for ſuch is the Diſtance of the Circle B *h*, which touches the Horizon, but has no Part of it below the Horizon.

Bodies leſs diſtant from the Pole, do not ſo much as come down to the Horizon.

3958. It appears by the ſame Reaſoning, that *Bodies, whoſe Diſtance from the oppoſite Pole does not exceed the Height of the Pole*, never riſe above the Horizon, and *are always inviſible.*

3959. *Bodies, whoſe Diſtance E Z from the Æquator is equal to the Height of the Pole, go through the Zenith* Z, for EZ is equal to the

* 3948. Latitude of the Place to which the Height of the Pole is equal *.

3960. *When a Spectator* S has receded as far as he can from the Pole,

Pl.125.F.5. he *comes to the Æquator* whoſe Points are equally diſtant from each

* 3933. Pole *; then the Axis P *p* is in the Horizon with which the Æquator

tor makes a right Angle*, for which Reaſon the *Horizon is ſaid to be right*; or this is called a *right Sphere*. * 3879. 3933.

The Horizon cuts into two equal Parts all the Circles, that are parallel to the Æquator, which are repreſented by the Lines A*a*, B*b*, therefore, *all the heavenly Bodies at every Revolution of the Earth, riſe and ſet, and are viſible and inviſible during equal Times.* 3961.

The Æquator itſelf *goes through the Zenith, and therefore all the Bodies that are in it paſs through it alſo.* 3962.

If what we have explained concerning the diurnal Motion be applied to the Bodies, of whoſe other apparent Motions we have ſpoken before, the Phænomena will be eaſily determined from the Motions joined together; thoſe that relate to the Sun are more remarkable than the reſt, and therefore more particularly to be explained. 3963.

Definition 18.

We call a natural Day the Time elapſed between the Receſs of the Sun from the Meridian of a Place, and it's next Return to the ſame Meridian. 3964.

This Day differs from the Time of the Revolution of the Earth above it's Axis, which Times would be equal, if the Sun appeared immoveable amongſt the fixed Stars: but whilſt by the diurnal Motion, in the Time of one Revolution of the Earth about it's Axis, the Sun is carried round from Eaſt to Weſt, that is *in Antecedentia* *, it is carried by a contrary Motion in the Ecliptic †, whereby it comes later to the Meridian. 3965. * 3886. † 3779.

But as the Sun does not every Day go through an equal Space in the Ecliptic *, all the *natural Days* do not equally exceed the Revolution of the Earth about it's Axis; therefore theſe Days *are unequal to one another*. 3966. 3967. * 3780.

Natural Days are unequal alſo upon another Account, namely, by Reaſon of the Inclination of the Ecliptic in Reſpect of the Æquator; whence it follows, that the annual Courſe of the Sun is unequally inclined to the Æquator in different Points; and though the Sun ſhould equally go forward every Day in the Ecliptic, the natural Days would not equally exceed the Time of the Revolution about the Axis; for if the Motion of the Sun be reſolved into two Motions *, of which the one is parallel to the Æquator *, and the other perpendicular to it, the firſt is only to be conſidered in determining the Exceſs abovementioned, and that it is unequal, is plain from the different Inclination abovementioned, as alſo the different Diſtance of the Sun from the Pole. 3968. * 1155.

Theſe

3969. Theſe two Cauſes of Inequality often concur, and often act contrarywiſe.

3970. *Every natural Day is divided into twenty-four equal Parts which are called Hours. Each Hour is divided into ſixty Minutes; and each Minute into ſixty ſecond Minutes; or Seconds, and ſo on.*

3971. *That theſe Parts of Time vary in different Days*, appears plainly
* 3967. from what has been * ſaid; they are by Aſtronomers reduced to
3972. Equality, by conſidering the Number of Hours in the whole Revolution of the Sun in the Ecliptic, and dividing the whole Time into as many equal Parts as there are Hours, twenty-four of which are taken for one Day.

Definition 19, and 20.

3973. *The Time whoſe Parts are* by this Method *reduced to Equality, is called the mean Time, and that Reduction is called the Æquation of Time.*

3974. *We always make uſe of the Days and Hours of the mean Time in determining the Periods of the heavenly Motions.*

Definition 21.

3975. The artificial Day *is the Time that the Sun ſtays above the Horizon.* We always ſpeak of it, when we mention Day in Oppoſition to Night.

3976. *In determining the Length of artificial Days, we do not attend to the Æquation of Time.*

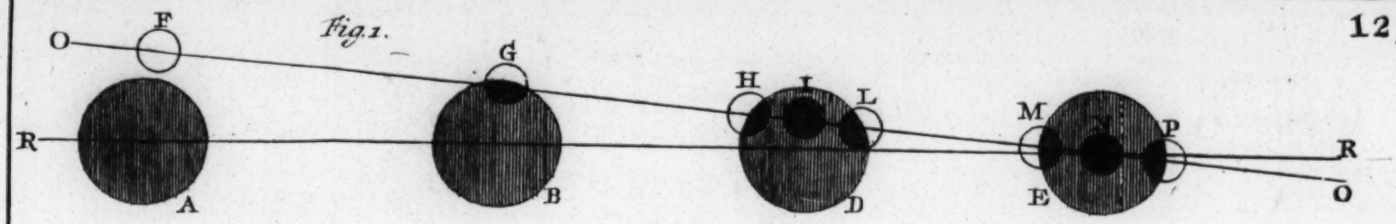
3977. *The Crepuſculum, or Twilight always comes before the Sun's Riſe, and follows it's ſetting; this is that dim Light which we commonly call Morning and Evening* Twilight.

3978. *The Twilight is produced by the Atmoſphere which is enlightned by the Sun's Rays, and whoſe Particles reflect the Light* every Way; from whence ſome Rays come to *us, though the Sun be depreſſed eighteen Degrees below the Horizon.*

3979. *In the right Sphere*, that is to all thoſe that dwell under the
* 3960. Æquator *, *the Days and Nights are equal to one another all the*
† 3961. *Year round* †, *and are of twelve Hours* *.
* 3970. *In the oblique Sphere the Days are longer or ſhorter, according to*
3980. *the different Diſtance of the Sun from the Æquator, towards either*
*3954. 3955. *Pole* *; for the Sun recedes from the Æquator towards the Poles
*3892. 3893. 23 Deg. 29 Min. *

3981. *The Sun is in the Æquator about the* 10*th of* March, *and the* 12*th*
* 3952. *of* September, *and then the Day is equal to the Night* *, *which happens all over the Earth, except juſt at the Poles.* Defi-

Fig. 1.



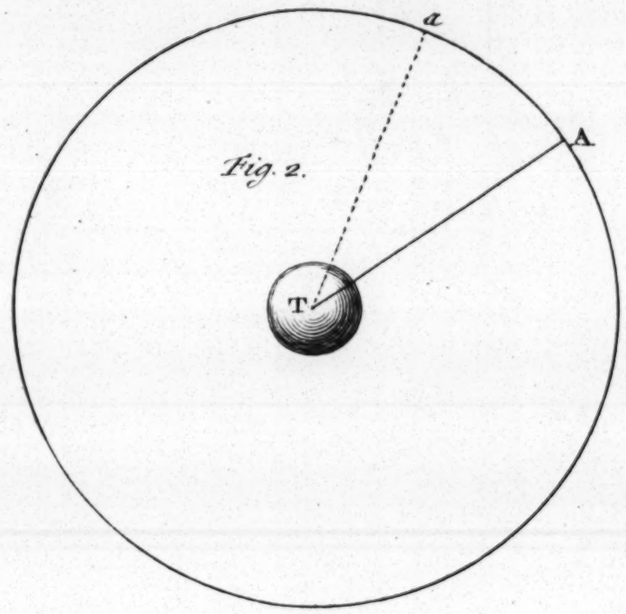


Fig. 2.

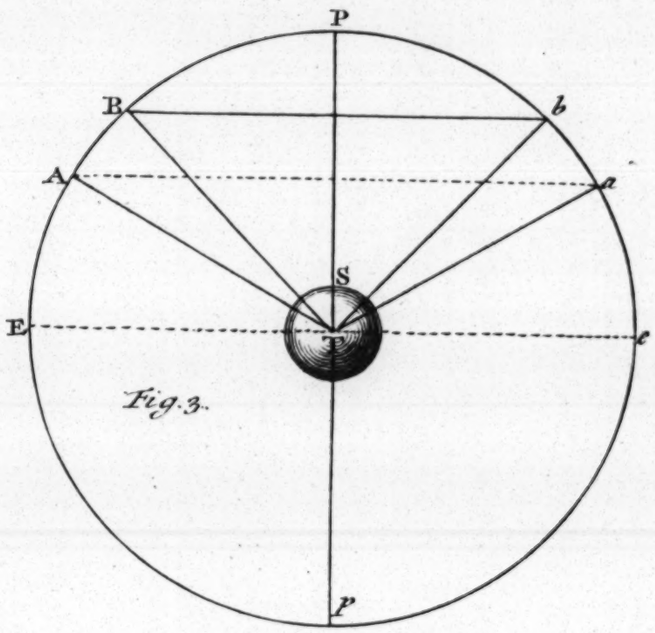


Fig. 3.

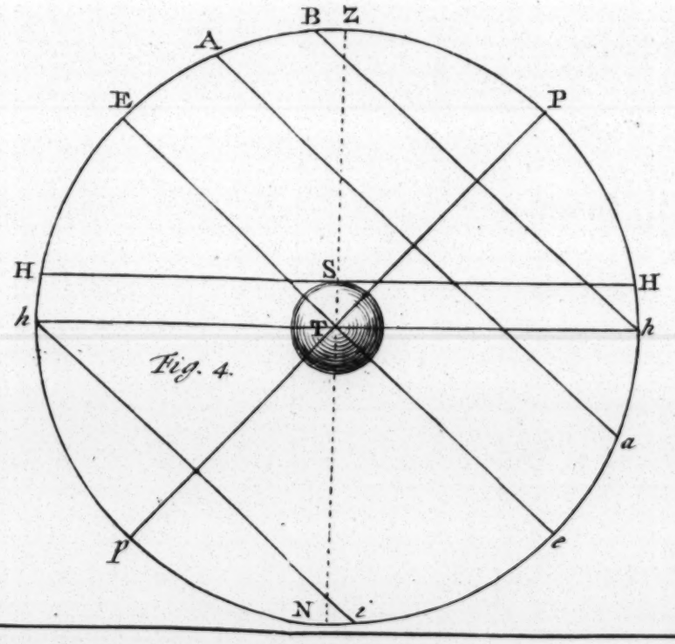


Fig. 4.

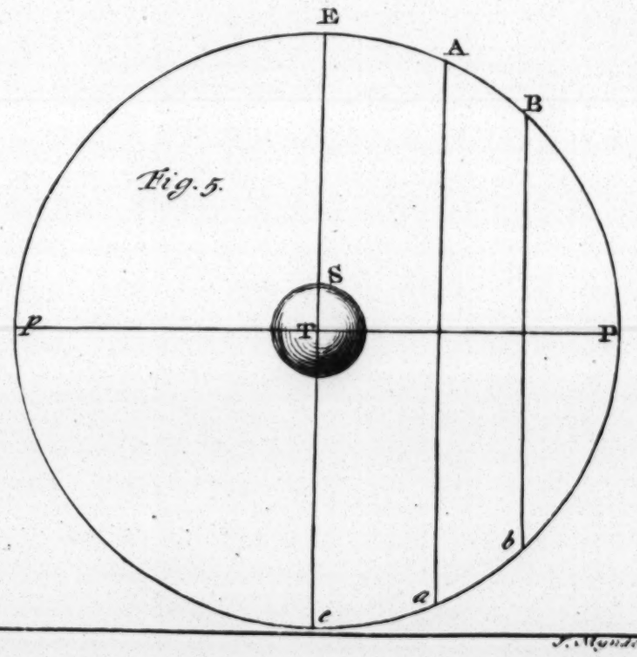


Fig. 5.

DEFINITION 22.

Thoſe Points of the Ecliptic in which it is cut by the Æquator *; *are called the Æquinoctial Points*, becauſe the Sun is in thoſe Points, when the abovementioned Equality of Day and Night happens. 3982. * 3890.

DEFINITION 23.

Theſe Points of the Ecliptic, in which the Tropicks touch that Circle *, *are called the Solſtitial Points*; becauſe for a few Days, when the Sun comes to thoſe Points, and goes beyond them, it does not ſenſibly change its Declination, and the Length of the Days does not ſenſibly vary. 3983. * 3894.

Under the Poles, if there be any Inhabitants there, they can only once in a Year ſee the riſing and the ſetting Sun, and *only one Day with one Night make up their whole Year*. The Sun continues above the Horizon all the while it goes through one half of the Ecliptic *, the reſt of the Time it is hid under the Horizon. But yet *their Day is lengthened upon account of the Refraction* *; *and the Twilights laſt very long*, for they laſt as long as the Declination of the Sun, towards the hidden Pole does not exceed 18 Deg. † 3984. * 3890. 3944. 3985. * 3931. † 3978.

In reſpect to the Arctic Pole, in the firſt ſix Signs, from *Aries* to *Libra*, the Sun is above the Horizon; therefore at the Pole *the Day exceeds the Night nine natural Days* *, *beſides the Diminution of the Night on Account of the Refraction* †. 3986. * 3784 † 3986.

Theſe general Things which relate to the different Poſitions of the Horizon being explained, ſome more particular Things are to be examined.

The whole Surface of the Earth is divided into five Zones. The firſt *is contained between the two Tropics* T T, *t t*, *and called the Torrid Zone*; *there are* two *Temperate Zones*, *and* two *Frigid Zones*. 3987. 3988. Plate 126.

The *Northern* Temperate Zone *is terminated by the* Tropic of *Cancer* T T, and the Arctic Polar Circle A A. The Southern Temperate Zone *is contained* between *t t*, the Tropic of *Capricorn*, and the Polar Circle *a a*. Fig. 2. 3989.

The Frigid Zones are circumſcribed by the Polar Circles, and the Poles are in the Centers of them. 3990.

In the Torrid Zone, twice a Year, the Sun goes through the Zenith at Noon *. For the Elevation of the Pole is leſs than 23 Deg. 29 Min. * and the Diſtance of the Sun from the Æquator towards the Pole, which is above the Horizon, is twice in a Year equal to the Height of the Pole *. For which Reaſon alſo in the Limits of 3991. * 3988. 3948. * 3892. 3893.

3992. that Zone, namely *under the Tropics, the Sun comes to the Zenith*
* 3892.3893. *only once in a whole Year* *.
3894.

3993. *In the Temperate and Frigid Zones*, the leaſt Height of the Pole
* 3892.3990. exceeds the greateſt Diſtance of the Sun from the Æquator *; and
3991. therefore to their Inhabitants *the Sun never goes through the Zenith* †.
† 3959. Yet *the ſame Day the Sun riſes to a greater Height, the leſs the Height*
3994. *of the Pole is*; becauſe thereby the Inclination of the Circles of the diurnal Motion with the Horizon is leſs.

3995. *In the Torrid Zone, and in the Temperate Zones, every natural Day*
* 3950.3955. *the Sun riſes and ſets**; for the Diſtance of the Sun from the Pole al-
* 3892.3989. ways exceeds the Height of the Pole *.

3996. Yet *every where but under the Æquator* * *the Artificial Days are*
* 3979. *unequal to one another* †; which Inequality is ſo much the greater,
† 3954.3956. the leſs the Place is diſtant from a Frigid Zone.

3997. *But in the Polar Circles*, juſt where the Temperate Zones are ſeparated from the Frigid ones, the Height of the Pole is equal to the Diſtance of the Sun from the Pole when it is in the neighbour-
* 3894. ing Tropic *; and therefore in that Caſe, that is, *once a Year, the*
3897. *Sun in its diurnal Motion performs one entire Revolution without go-*
* 3957. *ing down under the Horizon* *.

3998. *But every where in a Frozen Zone* the Height of the Pole is grea-
* 3894. ter than the leaſt Diſtance of the Sun from the Pole *; therefore
3990. *during ſome Revolutions of the Earth, the Sun* is at a Diſtance from the Pole, which is leſs than the Pole's Height, and during all that
* 3957. Time, it *does not ſet*, nor ſo much as touch the Horizon *. But where the Diſtance from the Pole, as the Sun recedes from it, does
* 3948. exceed the Height of the Pole or Latitude of the Place *, the Sun
† 3950. riſes or ſets every natural Day †; *then* in it's Motion towards the op-
3999. poſite Pole, *it ſtays in the ſame Manner, below the Horizon, as was*
* 3958. *ſaid of the Motion above the Horizon* *.

4000. Theſe Times, in which the Sun makes intire Revolutions above the Horizon, and below it, in it's diurnal Motion are ſo much
4001. the greater, that is, *the longeſt Day and Night laſt the longer, the leſs the Place in the Frigid Zone is diſtant from the Pole*, till at laſt,
* 3984. at the Pole itſelf, they take up the Time of the whole Year *.

4002. *From* the ſame Cauſes, namely, *the Obliquity of the Ecliptic in reſpect of the Æquator*, by which are occaſioned all the Things which relate to the Inequality of Days, which is different in different Places; *we* alſo *deduce the Difference of Seaſons, which ſucceed one another every Year*; I ſhall ſpeak of them firſt in reſpect to the Frigid and Temperate Zones, and then in reſpect to the Torrid Zone.

The

The Rays of the Sun communicate Heat to the Air, not only when they come directly from the Sun, but when they are reflected irregularly from Bodies or the Surface of the Earth *. 4003. * 2415.

This Effect is ſo much greater as the Rays ſtrike the leſs obliquely againſt the Surface of the Earth; and that upon a double Account. 1. If you reſolve the Motion of the Light into two Motions *, one of which is parallel, and the other perpendicular to the Surface of the Earth; the Light acts upon Bodies only by the laſt Motion, which diminiſhes as the Obliquity increaſes. 2. There are more Rays acting at one Time upon the ſame Part of the Surface of the Earth, the more directly they come upon it. * 1155.

Hence we deduce that *the Cauſes of Heat increaſe when the Days increaſe*, by the Sun coming towards the Pole which is above the Horizon; becauſe the Sun does daily aſcend to a greater Height; ſo that to the diminiſhed Obliquity is added the longer Continuance of the Sun above the Horizon, both which concur to the increaſing of the Heat; the Nights alſo are diminiſhed as the Days increaſe, and the Heat that is produced by Day has leſs Time to decreaſe in. 4004.

In the Northern Zones, as follows from this, the Cauſe of the Heat is the greateſt of all, when the Sun comes to the Tropic of *Cancer* *. *Yet the Heat is not always the greateſt where the Cauſe of Heat is the greateſt*; for the Heat increaſes as long as that which is acquired by Day is not wholly deſtroyed by Night; for though the daily Augmentations be diminiſhed, as long as there is an Augmentation the Heat increaſes. *The moſt intenſe Cold is not upon the ſhorteſt Day*, in which the Obliquity of the Sun's Rays is the greateſt, and the Abſence of the Sun the longeſt; but the Cold increaſes, as long as the Diminution of the Heat does laſt; concerning which one may reaſon in the ſame Manner as concerning the Increaſe of Heat. 4005. * 3896. 4006. 4007.

The Year is divided into four Seaſons; the hotteſt is called the Summer; the coldeſt the Winter; the temperate Seaſon that follows the Winter, Spring; and the Autumn comes between Summer and Winter. 4008.

In the Northern Regions, in the Beginning of Spring, the Sun appears to be in the Beginning of Aries; in the Beginning of Summer the Sun comes to the Tropic of Cancer. When the Sun enters Libra, the Autumn begins: In the Beginning of Winter the Sun performs it's diurnal Motion in the Tropic of Capricorn; all which may be eaſily deduced from what has been explained *. 4009. * 4006,4007.

4010. *In the Southern Regions the Summer happens in the the Time of Winter abovementioned, and they have their Spring whilſt the former have their Autumn; and ſo of the other Seaſons.*

The general Cauſes, upon which the Diviſion abovementioned depends, are often diſturbed by Cauſes relating to particular Places:
4011. eſpecially *in the Torrid Zone*, of which we ſaid we muſt treat ſeparately. In moſt Places of this Zone *there are only two Seaſons obſerved* (viz.) *Summer and Winter, which are* chiefly *diſtinguiſhed by dry and wet Weather.*

4012. *When the Sun comes to the Zenith of any Place*, there are almoſt continual Rains, upon which Account *the* Heat is diminiſhed,
4013. which *Time is referred to, or called Winter. As the Sun recedes*, the Rains diminiſh, *the Heat is increaſed, and that Time is referred to Summer.*

4014. *In the Middle of the Torrid Zone, there are two Summers, and as*
* 3991. *many Winters*; becauſe the Sun comes up twice to the Zenith *.

4015. Towards the Sides of this Zone, though the Sun comes twice to the Zenith; yet ſince there is but a ſmall Time between it's coming to it the firſt and ſecond Time, both the Winters are confounded into one, wherefore only two Seaſons in a Year are obſerved there.

CHAP. IX.

Concerning the Phænomena ariſing from the Motion of the Axis of the Earth.

4016. WE have ſaid that the Axis of the Earth is carried by a
* 3721. parallel Motion *; we have not conſidered a ſmall Motion, whereby it is really moved, of which we ſhall now ſpeak.

4017. *The Axis of the Earth, keeping the Inclination of* 66 Deg. 31 Min. *to the Plane of the Ecliptic, revolves in Antecedentia*, that is, is ſucceſſively carried towards all Parts; *and* it's Extremities, (viz.)
4018. *the Poles of the World deſcribe Circles round the Poles of the Ecliptic*, from Eaſt to Weſt. And *this Revolution is performed in the Time of about* 26000 *Years, which Period is called the Great Year.*

4019. Becauſe the Earth is looked upon as immoveable by it's Inhabitants, this Motion is referred to the heavenly Bodies, as has been ſaid of the other Motions. Therefore whilſt the Poles of the World are moved about the Poles of the Ecliptic in *Antecedentia*,

and paſs ſucceſſively through all the Points that are 23 Deg. 29 Min. diſtant from theſe Poles, theſe Points themſelves, or rather the fixed Stars that are in them, come towards the Poles of the World ſucceſſively, and ſeem to be carried in *Conſequentia*, and to deſcribe Circles which are really deſcribed by the Poles of the World about the Poles of the Ecliptic, which, being placed in Centers, alone are at reſt. For together with the Stars abovementioned the reſt of the Stars (becauſe they keep the ſame Situation in reſpect to one another) * do alſo appear to be moved. * 3689.

Therefore *the* whole *Sphere of the fixed Stars ſeems to move, in* Conſequentia, *about an Axis paſſing through the Poles of the Ecliptic*; and each Star apparently deſcribes a Circle parallel to the Ecliptic; by which Motion the Latitude of the Stars is not changed. 4020.

The Plane of the Æquator makes a right Angle with the Axis of the Earth; therefore, by the aforeſaid Motion of its Axis, the Section of the Plane of the Æquator, with the Plane of the Ecliptic, is moved round; wherefore *the firſt Points of Aries and Libra**, which are always oppoſite, move through the whole Ecliptic Line *in the Space of about* 25920 *Years in Antecedentia:* Yet they are looked upon as immoveable by the Inhabitants of the Earth, who imagine that the fixed Stars themſelves are moved in *Conſequentia**. 4021. * 3890. * 4020.

This Tranſlation of the firſt Point of Aries and Libra, which is called the *Præceſſion of Æquinoxes*, is the Reaſon why the Sun, when it has receded from one of theſe Points, returns to it again before it has performed one intire Revolution in the ecliptic Line: But as the Æquinoxes determine the Vulgar or Ecliptic Year, the periodical Time of the Earth exceeds that Year *. 4022. * 3729.

CHAP. X.

Concerning the fixed Stars.

WE have ſaid that the fixed Stars are lucid Bodies, removed ſo far off, that their Diſtances can be compared with no Diſtances in the planetary Syſtem. For *Aſtronomers have not been able, by their niceſt Obſervations, to obſerve the Poles of the World carried out of their Place in the annual Motion of the Earth* *, although they deſcribe Circles in the Heavens which are equal to the Earth's Orbit *. 4023. 4024. * 2654. * 3721.

DEFINITION I.

4025. This Motion of the Pole is called the *annual Parallax.*

4026. That the fixed Stars are at an immenſe Diſtance, it is alſo proved
4027. by Obſervations with the Help of Teleſcopes, *if any fixed Star*, even the lucid and conſpicuous, *be beheld with a Teleſcope*, through which the Diameter of the Sun would appear equal to the Diameter of the Earth's annnal Orbit, *it will appear to be a lucid Point, without any ſenſible Magnitude*; for all the fixed Stars appear leſs when they are ſeen through Teleſcopes, than they do to the naked Eye; for 'tis only their Twinkling which makes them appear to have any ſenſible Magnitude.

4028. *That the Stars may be diſtinguiſhed, they are referred to various Figures, which are imagined in the Heavens, and are called Conſtellations.*

4029. *Twelve Conſtellations are imagined to be in the Zodiac, which are called the Signs of the Zodiac*; they receive their Names from the Animals or Things which they repreſent: *Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, Aquarius, Piſces.*

4030. *Theſe Signs have given their Names to twelve Parts of the Ecliptic,*
* 3783. of which we have ſpoken before *.

In the Time of *Hipparchus*, the Sections of the Ecliptic and Æquator were between the Conſtellations of *Piſces* and *Aries*, and *Virgo* and *Libra*, and the Conſtellations gave their Names to thoſe Parts of the Ecliptic, which paſſed through each Conſtellation,
4031. and *the Parts of the Ecliptic ſuppoſing the Beginning of* Aries *and* Libra, *in the Interſections of the Æquator and the Ecliptic, have kept the Names which they had* at that Time, *though theſe Interſections be*
* 4021. *carried from their old Places* *; whence the Sun is ſaid to be in *Taurus*, when it moves amongſt the Stars of the Conſtellation *Aries.*

4032. The Zodaic ſeparates the North Part of the Heavens from the South Part.

4033. *In the Northern Region are the following Conſtellations: the leſſer Bear, the greater Bear, the Dragon, Cepheus, the Hounds, Bootes, the Northern Crown, Hercules, the Harp, the Swan, the Lizzard, Caſſiopeia, Camelopardus, Perſeus, Andromeda, the Triangle, the leſſer Triangle, the Fly, Auriga, Pegaſus, or the Flying-Horſe, Equuleus, the Dolphin, the Fox, the Gooſe, the Arrow, the Eagle, Antinous, Sobieſky's Shield, Serpentarius, the Serpent, Mount Mænalus, Berenice's Hair, the leſſer Lion, the Lynx.*

In

In the Southern Region of the Heavens, are the following Conſtellations, many of which are inviſible to us * *: namely the Whale, the River Eridanus, the Hair, Orion, the great Dog, Rhinoceros, the leſſer Dog, the Ship Argo, Hydra, the Sextant of Urania, the Cup, the Crow, the Centaur, the Wolf, the Altar, the Southern Crown, the Southern Fiſh, the Phœnix, the Crane, the Indian, the Peacock, the Bird of Paradiſe, the Southern Triangle, the Croſs, the Fly, the Chamælean King,* Charles's *Oak, the flying Fiſh, the* Toucan *or* American *Gooſe, Hydrus, or* the Water Serpent, *Xiphias, or* the Sword Fiſh. 4034. * 3958.

Definition 2.

The Stars, which are between the Conſtellations, are called unformed Stars. 4035.

The Stars are not equally lucid, and they are referred by Aſtronomers *to ſix Claſſes,* the moſt lucid are called Stars of the firſt Magnitude; others are ſaid to be Stars of the ſecond Magnitude, others of the third, &c. to the ſixth Magnitude. 4036.

Some are not referred even to this laſt Claſs, and are called Nebulous Stars. 4037.

There is alſo *a* certain *Zone* or Belt obſerved *in the Heavens, which* is not every where of the ſame Breadth, and goes round the whole Heavens, and in ſome Places is ſeparated, ſo as to become double. From its Colour it *is called the milky Way.* It is plain from Obſervations by the Teleſcope, that *this Way is an Aſſemblage of innumerable fixed Stars, which cannot be ſeen by the naked Eye,* either becauſe they are leſs than the other Stars, or more diſtant. 4038. 4039.

Towards the Antarctic Pole there are two Nubeculæ, of the ſame Colour as the Milky Way, which are alſo Heaps of ſmall Stars, and cannot be ſeen without a Teleſcope. Beſides the Stars, which are obſerved in theſe Nubeculæ, and in the Milky Way, *to whatſoever Parts of the Heavens you point the Teleſcope, you may diſcover ſmall Stars in a great Number which are not viſible to the naked Eye.* Very often an Heap of Stars appears to the naked Eye to be but one Star. 4040. 4041.

Amongſt the Stars, ſome are viſible and inviſible by Fits, and obſerve regular Periods; others are ſucceſſively ſometimes more lucid, ſometimes of a duller Light, and to be ſeen only by the Help of a Teleſcope, and that at certain Times. 4042.

Yet they are not equally bright at every Period. Sometimes Stars have appeared ſuddenly, exceeding the brighteſt in Light, which afterwards, 4043.

terwards, ſucceſſively decreaſing, have vaniſhed in a ſhort Time, and ſtill remain inviſible.

4044. Beſides the Stars, *we obſerve in the Heavens ſeveral whitiſh Spots, which are in ſome Meaſure lucid and inviſible to the naked Eye*; their Light is referred to the Stars which are in them, or they are looked upon as nebulous Stars.

What theſe Spots are cannot be determined; perhaps they are a Congeries of Stars, which have the ſame Relation to the Teleſcopick Stars, as thoſe which form the Milky Way have to thoſe which are ſeen by the naked Eye.

Mathematical Elements

OF

NATURAL PHILOSOPHY

CONFIRM'D BY

EXPERIMENTS.

BOOK VI.

PART II. The Phyſical Cauſes of the Celeſtial Motions.

CHAP. XI.

Concerning univerſal Gravity.

HAVING explained the Motions of the heavenly Bodies, and the Phænomena ariſing from them, we muſt now examine by what Laws theſe Motions are performed. 4045.

We have before laid down the Laws according to which the Motions of Bodies are directed *. If we add one to theſe, we ſhall ſee the whole Contrivance by which that vaſt Machine, the Planetary Syſtem, is governed. 4046.

* 355. 356. 361.

The Law to be added to the reſt, is this. *All Bodies are mutually heavy* (or gravitate) *towards each other.* 4047.

This Gravity is proportional to the Quantity of Matter. 4048.

At unequal Diſtances it is inverſly as the Square of the Diſtance. 4049.

That

4050. That is, all Bodies mutually attract or tend towards each other, with the Force which belongs to each Particle of Matter acting upon each Particle; and the Force, with which a Body acts upon others, is compounded of the joint Forces of all the Particles of which the Body conſiſts; ſo this Force increaſes in the Proportion of the Quantity of Matter, and is unchangeable in every Particle; it is always the ſame at the ſame Diſtance; but the Diſtance increaſing, the Force decreaſes as the Square of the Diſtance increaſes.

4051. *We call this Force Gravity, when we conſider a Body which of itſelf tends towards another*; becauſe this Force is called by this Name
* 148. near the Earth's Surface *.

4052. *But when we conſider a Body, towards which another tends, we call the Force Attraction.* We mean the ſame Effect by theſe Names,
* 361. and nothing but the Effect; for ſince all Gravity is reciprocal *, it
365. is the ſame to ſay, all Bodies gravitate mutually towards one another, as that Bodies mutually attract one another, or mutually tend towards each other.

4053. We look upon this Effect as a Law of Nature *; becauſe it is conſtant, and its Cauſe is unknown to us, and cannot be deduced from Laws that are known, as we ſhall ſhew by and by. Now that there is ſuch a Gravity, is to be proved from Phænomena.

4054. *All the primary Planets are kept in their Orbits by Forces, which*
* 586. *tend towards the Center of the Sun* *; therefore there is a Force by
3712. which the Planets are carried towards the Sun, and whereby the
* 361. Sun tends reciprocally towards each of them *: That is, *the Sun
365. and Planets gravitate mutually towards each other.*

4055. After the ſame Manner it is plain, that *the Satellites of Jupiter and Jupiter gravitate towards each other; as alſo that the Satellites of Saturn gravitate towards their primary Planet, and that towards*
* 586. *them* *.
3739. 365. *The Moon and the Earth alſo gravitate towards each other.*

4056. *All the ſecondary Planets gravitate towards the Sun.* For they
* 588. 3739. 365. are all carried by a regular Motion about their primary Planets, as
4057. if the primary Planets were at reſt; whence it is plain, that they are carried about by the common Motion with the primary Planets; that is, that the ſame Force, by which the primary Planets are every Moment carried towards the Sun, acts upon *the ſecondary ones*, and that they
4058. *are carried towards the Sun with the ſame Celerity as the primary Planets.*

Even

Even the Irregularities of the ſecondary Planets, which are ſo ſmall, as only to be ſenſible with reſpect to the Moon, confirm this Gravity of the ſecondary Planets towards the Sun; for we ſhall ſhew hereafter, that all the Irregularities are cauſed by the Change of the Moon's Gravity towards the Sun, at a different Diſtance; and becauſe the Lines, in which the Earth and Moon tend towards the Sun, are not altogether parallel. 4059. 4060.

From the Gravity of the ſecondary Planets towards the Sun, it follows, that *the Sun gravitates towards them* *. * 361. 365.

In reſpect of the Gravitation of the primary Planets towards one another, Aſtronomers have obſerved that *Saturn* changes its Way a little when it is neareſt to *Jupiter*, which is far the greateſt of all the Planets; ſo that it is plain from immediate Obſervations, that *Jupiter and Saturn gravitate towards each other.* 4061. 4062.

Saturn alſo in this Caſe, as *Flamſteed* has obſerved, diſturbs the Motion of *the Satellites of Jupiter*, attracting them a little to itſelf; which proves that theſe Satellites *gravitate towards Saturn, and Saturn towards them.* 4063. 4064. 4065.

Having compared together all that has been ſaid from N° 4054 to 4062. it follows, that the ſeventeen Bodies, of which the planetary Syſtem is made up, mutually gravitate towards each other, although no immediate Obſervations can be made concerning the Gravitation of each particular one towards the reſt *. * 11.

The ſecond Part of the Law is *, that Gravity is proportional to the Quantity of Matter; that is, that all the Particles of Matter gravitate towards each other; and therefore that the Law of Gravity is univerſal, and that every Body acts upon all other Bodies; which is deduced from Phænomena. 4066. * 4048.

The Forces of Gravity are as the Actions produced in the ſame Time *, and thoſe Actions, if the Tranſlations are equal, are to one another, as the Quantities of Matter in the Bodies transferred*; therefore ſince unequal Bodies at the ſame diſtance from the attracting Body, move equally ſwift by Gravity *, it is evident, that the Forces of Gravity are proportional to the Quantity of Matter *. 4067. * 126. * 131. 132. * 4057.

We find the ſame in all Bodies *near the Earth's Surface*, which have a Gravitation towards the Earth, proportional to their Quantity of Matter *. 4068. * 156.

But *the mutual Gravity of all* theſe *Bodies towards one another is not ſenſible*; becauſe it is exceeding ſmall in reſpect to their Gravity towards the Earth; and therefore cannot diſturb their Motion ariſing

from their Gravity towards the Earth; at leaſt, ſo as to make any ſenſible Change in the Direction of their Motions.

4069. We ſhall preſently ſhew, by another Method, that this univerſal Gravity of all the Particles of Matter, whereby they act upon
* 4072.4074. one another, may be proved from Phænomena *.

4070. The third Part of the Law, which we examine, is, that Gravity decreaſes when the Diſtance increaſes, and is inverſly as the Square of the Diſtances, which alſo follows from Phænomena.

4071. Bodies, upon which Gravity acts according to their Quantity of Matter, as in our Syſtem, are moved with an equal Celerity in the ſame Circumſtances, as we ſaid before; ſo that it is no Matter, whether the Bodies are greater or leſs; and they are moved as if they were equal: But in this Caſe, if the Force towards a Point decreaſes in an inverſe Ratio of the Square of the Diſtance from that Point, and the Bodies move at various Diſtances from it, and are kept in Circles by that Force; the Squares of the Periodical Times
* 621. 623. will be to one another, as the Cubes of the Diſtances *. Which is demonſtrated by Geometers to obtain (in reſpect of the mean Diſ-
* 627. tances) in Elliptic Lines, whoſe Forces are directed to their *Foci* *. But this is the Caſe in Bodies which revolve about the Sun, *Saturn*
* 3747. and *Jupiter* *; whence it follows, that the Force of Gravity, receding from the Centers of theſe Bodies, decreaſes in an inverſe Ratio of the Squares of the Diſtances.

4072. By this Reaſoning ſuppoſing Gravity proportional to the Quantity of Matter, we demonſtrate, that it decreaſes in an inverſe Ratio of the Square of the Diſtance. And by the ſame Reaſoning, ſuppoſing the Diminution of Gravity to be in this Proportion it follows, that Gravity is proportional to the Quantity of Matter as is very evident.

4073. But we prove by another Argument, that the Diminution of Gravity ſo often mentioned, is in an inverſe Ratio of the Square of the Diſtance; ſo that there can remain no Doubt concerning the two Laws of Gravity, which we now treat of.

4074. The Planets are moved in Orbits at reſt *; and are kept in them
* 3696. by Forces, which are directed to an excentric Point †; but it is
† 3097.4054. plain, that this would not obtain, if the central Force did not in-
* 637. creaſe in an inverſe Ratio of the Square of the Diſtance *.

4075. It follows from the ſame Reaſoning, that receding from the Center of the Earth, Gravity decreaſes according to the ſame Law. For the Moon is retained in it's Orbit by a Force which tends
* 586. 3739. towards the Center of the Earth, that is to an excentric Point *:
3740.

and

and though the Line of the Apſides is not carried by a parallel Motion, it's Agitation is ſo ſmall, if we conſider every Revolution, that it may be looked upon here as quieſcent: In the 16th Chapter we ſhall compute the Force which keeps the Moon in its Orbit ſo agitated, and we ſhall find the Diminution of the Force of Gravity, in reſpect of the Moon, to differ very little from an inverſe Ratio of the Square of the Diſtance, and we ſhall ſhew hereafter, that this Difference depends upon the Action of the Sun.

And no Doubt will remain concerning this Diminution, if we conſider, *that the Moon is kept in it's Orbit by that very Force, wherewith Bodies are carried towards the Earth, near the Earth's Surface*; which is diminiſhed according to the Law of Diminution ſo often mentioned. 4076.

The mean Diſtance of the Moon is $60\frac{1}{2}$ Semidiameters of the Earth: that is 60, 50. Let us ſuppoſe it to be 60, 522; which Correction is ſmall, if we conſider alſo that this that we ſuppoſe is a Mean between ſeveral mean Diſtances determined by different Aſtronomers. We have before ſhewn, that a Diameter of the Earth contains 3389940 *Rhynland* Perches *; whence knowing the periodical Time ‡, of the Moon, we eaſily diſcover that the Moon, in one Minute of Time, goes through 196594 *Rhynland* Perches of her Orbit. This Arc is not the hundredth Part of one Degree, and may be looked upon as it's Subtenſe; therefore the Diameter of it's Orbit is to this Arc; as the Arc itſelf is to it's verſed Sine, which is diſcovered to be of 15,6982 *Rhynland* Feet, and it is the Space which the Moon and Earth would go through in one Minute, coming to one another by their mutual Attraction. 4077. * 3750. ‡ 3743.

But as we have obſerved, the Gravity of the Moon to the Earth is changed by the Sun's Action; and as we ſhall ſhew in the 16th Chapter, the Effect of the whole Action coincides with the Diminution of the Gravity, which is to the Gravity itſelf, as 1 to 180,66; wherefore the Space 15,6982 muſt be increaſed in that Proportion, that the Diminution from the Action of the Sun may be taken away, and then it will be 15,7851 Feet.

The Space gone through by a Body which Gravity cauſes to come towards another, depends upon the Force by which it is attracted by it, all whoſe ſingle Particles of Matter attract it *; therefore the Spaces run through by the Moon and the Earth, in their Acceſs, are inverſely as the Quantity of Matter in them. Therefore as the Quantity of Matter in both the Bodies of the Moon and Earth together, is to the Quantity of Matter in the Earth; ſo is the 4078. * 4066.

Space run through by both in their mutual Acceſs, to the Way run through by the Moon alone. But the Quantities of Matter in the Moon and Earth, as we ſhall ſhew in the laſt Chapter, are to one another as 1 and 39,31., and 40,31, is to 39,31., as 15,7851. to 15,3935., the Space run through by the Moon; which therefore any Body would go through toward the Earth in one Minute, ſetting out at the Diſtance of the Moon *.

* 4067.

4079. This Force increaſing in the inverſe Ratio of the Squares of the Diſtances, the Space run through at the ſame Time at the Diſtance of one Semidiater of the Earth, that is in it's Surface, will be of 60,522 × 60,522 × 15,3935 Feet; but becauſe in every Motion equably accelerated, as here, (for we conſider the Force at the Diſtance of the Surface of the Earth from it's Center) the Squares of the Times are, as the Spaces run through in their Fall *, dividing that Number by 60 × 60, that is 3600, we have the Space run through by a Body in a ſecond Minute near the Earth, by the Force with which the Moon is retained in it's Orbit, which is found to be 15,6625 *Rhynland* Feet.

* 374.

4080. Now if we examine the Gravity which we experience every Day in all Bodies on the Surface of the Earth *; from what has been demonſtrated concerning the Motion of Pendulums ‡, and by very accurate Experiments made at *Paris* and in *Lapland* upon Pendulums, it appears, that Bodies under the Poles in one Second fall 15,6743 *Rhynland* Feet; and under the Æquator 15,5966 Feet. But Bodies under the Æquator are directly puſhed upwards by the centrifugal Force; and as every Point of the Æquator in one Minute goes through 1487,44 Feet, as is certain from the known Time of the Revolution of the Earth, and the known Diameter of the Æquator, which we determine in the 17th Chapter, as alſo ſince the verſed Sine of that Arc is of 0,0542 Feet, this Sine ſhews the Space, which Bodies aſcending by the centrifugal Force, in one Second would go through if they were not hindered by Gravity. Gravity is diminiſhed by the Action of that centrifugal Force, which being ſet aſide, Bodies under the Æquator would in one Second run through 15,6508 Feet by Gravity. Therefore Bodies by Gravity which is a Mean between this Gravity and that at the Pole, will go through 15,6625 in *Rhynland* Feet in one Second. And this Gravity is the very ſame Force which retains the Moon in it's Orbit.

* 147.

‡ 415.

4081. We have conſidered the Centers of the Bodies in examining the Law of the Diminution of Gravity, although Gravity belongs to all

the Particles of Bodies; becauſe it is plain by the Mathematical Demonſtration, which we ſhall give in the next Scholium, that *the Action of a ſpherical Body (in which, in every Part, the Particles, that are equally diſtant from the Center, are homogeneous, and which is made up of Particles, towards which there is a Gravity that decreaſes, receding from each of them in an inverſe Ratio of the Square of the Diſtance) is directed towards the Center of the Body, and receding from it, is diminiſhed in the ſame inverſe Ratio of the Square of the Diſtance:* So that ſuch a Body acts, as if all the Matter, of which it conſiſts, was collected in it's Center. Whence we deduce the following Concluſions. 4082.

That *on the Surfaces of Bodies, in which the Matter is homogeneous at equal Diſtances from the Center, the Gravity is directly as the Quantity of Matter in the Bodies* *, *and inverſly as the Squares of the Diameter* ‡; for in theſe Bodies the Diſtances from the Center are as the Diameters. 4083. * 4048. ‡ 4049.

That *on the Surfaces of Bodies that are ſpherical, homogeneous, and equal, the Gravities are, as the Denſities of the Bodies*; for the Diſtances from the Center are equal; in which Caſe the Forces of Gravity are as the Quantities of Matter *; which in equal Bodies, are as their Denſities ‡. 4084. * 4048. ‡ 1463.

That *on the Surfaces of the Bodies, that are ſpherical, unequal, homogeneous, and equally denſe, the Gravities are* inverſly as the Squares of the Diameters, becauſe the Diſtances from the Center are *in the Ratio* of thoſe Diameters *, the Gravities alſo are directly as the Cubes of their Diameters ‡; for the Quantities of Matter in Spheres are in that Ratio *: And the Ratio compounded of that direct Ratio of the Cubes of the Diameters, and the inverſe Ratio of the Squares, is the direct Ratio *of the Diameters themſelves.* 4085. * 4049. ‡ 4048. * 18. El. xii.

Therefore *if both the Denſities and the Diameters differ, the Gravities on the Surface will be in a Ratio compounded of the Denſities* * *and the Diameters* ‡. Therefore dividing the Gravity on the Surface, by the Diameter, you will have *the Denſity*; which conſequently *is in a direct Ratio of the Gravity on the Surface, and an Inverſe Ratio of the Diameter.* 4086. * 4084. ‡ 4085. 4087.

If a Body be placed in a Sphere that is homogeneous, hollow, and every where of the ſame Thickneſs, whereſoever it be placed it has no Gravity, the oppoſite Gravities mutually deſtroying one another, as we ſhall ſhew in the next Scholium: 4088.

Whence it follows, that *in an homogeneous Sphere*, a Body, coming towards the Center, gravitates towards the Center only from the Action 4089.

Action of the Sphere, whoſe Semidiameter is the Diſtance of the Body from the Center, which *Gravity decreaſes in coming towards*
* 4085. *the Center, in the Ratio of the Diſtance from the Center* *; for all Matter which is at a greater Diſtance from the Center, forms an hollow Sphere, in which the ſeveral Actions on a Body deſtroy
* 4088. each other *.

4090. We have ſaid that the Gravity which we have hitherto explained is to be taken for a Law of Nature, becauſe we don't know the Cauſe of it; and becauſe it depends upon no Cauſe that is known to us, which will evidently appear, if we attend to what follows.

4091. *(Viz.)* That *Gravity requires the Preſence of the attracting Body*; ſo the Satellites of *Jupiter*, ex. gr. gravitate towards *Jupiter* where-
* 4055. ſoever it be *.

4092. That *the Diſtance remaining the ſame, the Celerity with which Bo-*
4093. *dies are carried by Gravity, depends upon the Quantity of Matter in*
* 4067. *the attracting Body* *: *And that the Celerity is not changed, let the Maſs of the gravitating Body be what it will* *.

4094. Beſides that, *if Gravity depends upon any known Law of Motion, it ought to be referred to a Stroke from an extraneous Body*; and becauſe Gravity is continual, *a continual Stroke would be required.*

4095. If there be ſuch a Sort of Matter continually ſtriking againſt Bodies, it muſt of Neceſſity be fluid, and very ſubtile, ſo as to penetrate all Bodies; for Bodies, that are any how ſhut up in others, are heavy.

4096. Now let a Mathematician conſider, whether a Fluid ſo ſubtile, as freely to penetrate the Pores of all Bodies, and ſo rare, as not ſenſibly to hinder the Motion of Bodies (for in a Place void of Air the Motion of a Pendulum will be continued very long) can impel vaſt Bodies towards one another with ſo much Force?

4097. Let him explain how this Force increaſes in a Ratio of the Maſs
* 4092. of the body towards which another is carried *.

4098. Laſtly let him ſhew, what ſeems moſt difficult to me, how all Bodies, in any Situation whatſoever (if the Diſtance, and the Body towards which the Gravitation is, remain the ſame) are carried
* 4093. with the ſame Velocity *; that is how a Liquid which can only act on the Surfaces, either of the Bodies themſelves, or their internal Particles, to which it is not hindered from coming by the Interpoſition of other Particles, can communicate ſuch a Quantity of Motion to Bodies which in all Bodies exactly follows the Proportion of the Quantity of Matter in them; and which in this Chapter we

have proved to obtain every where in Gravity, and which we have demonſtrated by a direct Experiment in reſpect of the Gravity near the Earth's Surface *. * 2240.2252.

Yet we don't ſay, that *Gravity does not depend upon any Stroke*, but that it does not follow from that Stroke, *according to any Laws known to us*, and we confeſs that we are intirely ignorant of the Cauſe of Gravity. 4099.

SCHOLIUM.

Of Gravity towards a Sphere, whether ſolid or hollow.

LET us ſuppoſe the Particle of Matter A to be attracted by an hollow Sphere HPN, which is homogeneous and every where of the ſame Thickneſs, whoſe Center is C; let us ſuppoſe alſo, that all the Particles of Matter of which the Sphere conſiſts, draw the Particle A according to the Laws of Gravity above mentioned *. We ſhall demonſtrate, that the Attraction is the ſame, whether the Sphere be greater or leſs, provided it contains the ſame Quantity of Matter, and has the ſame Center. 4100. Plate 126. Fig. 1. * 4047. 4048. 4049.

Let C be that Center, as we have ſaid; HN the Diameter of the Sphere, having drawn at Pleaſure the Lines AP, *a p*, containing an infinitely ſmall Angle, we conceive that they have a Rotation about the Axis AC, and, while they run over the Surfaces of Cones, that they determine in the Surface of the Sphere a Ring, whoſe Semidiameter is BG, and Breadth B*b*: we alſo ſuppoſe that the Thickneſs is inverſely as the Surface of the Sphere; that is inverſely as the Square of the Radius BC; becauſe we ſuppoſe that having changed the Sphere, the ſame Quantity of Matter remains; ſo that the Thickneſs is increaſed as the Diameter of the Sphere is diminiſhed. 4101.

The Quantity of Matter, in that Ring, is then as $\frac{B b \times BG}{BC^2}$. The Force by which the Ring attracts to itſelf the Particle A is in that Ratio *, and inverſely as the Square of the Diſtance BA †; wherefore $\frac{B b \times BG}{BC^2 \times BA^2}$ † would expreſs the Force of the Ring, if that Force was not oblique; but by Reaſon of the Obliquity it is leſs in the Ratio of AB to AG *, or AC to AD, having drawn CD perpendicular to AP. 4102. * 4043. † 4049. * 311.

For the rectangular Triangles ACD, ABG, which have a common Angle at A, are ſimilar *. Therefore we may expreſs thus the Force of the Ring $\frac{B b \times BG \times AD}{AB^2 \times BC^2 \times AC}$. * 4 El. 6. 4104.

Let us conceive the Sphere, keeping the ſame Center and Quantity of Matter, to be diminiſh'd ſo that the Diameter may become IM; now drawing 4105.

drawing the Lines AQ, Aq, containing a ſmall Angle; and having made them move round, as we ſaid of AP, Ap, we cut off a Ring whoſe Radius is FL, and it's Breadth Ff, the Thickneſs inverſely as the Square of the Semidiameter FC; and the whole Force with which the Ring will attract the Particle A, drawing CE perpendicular to AQ, will be as $\frac{F f \times FL \times AE}{AF^2 \times CF^2 \times AC}$ *.

* 4104.

4106. Now if the Arcs BP, FQ, as alſo bp, fq, are ſimilar, it will appear by the following Demonſtration that the Forces of the ſaid Rings are equal.

4107. Becauſe of the infinitely ſmall Angle PAp, the Line CD, which is perpendicular to BP, is alſo looked upon as perpendicular to bp; ſo alſo CE, or Ce, is looked upon as perpendicular to fq; and, becauſe in

* 4106. thoſe different Circles the Chords are correſpondent *, therefore the Perpendiculars on them from the Center are proportional;

That is, CD, Cd :: CE, Ce.

4108. By Diviſion and Altern. CD, CE :: Dd, Ee.

* 4103. We have beſides CD, AC :: BG, AB *.

4109. As likewiſe AC, CE :: AF, FL.

* 4106. Whence by joining the Ratios CD, CE, or CB, CF* :: BG × AF, AB × FL.

Therefore CB × AB × FL = CF × BG × AF; whence $\frac{BG}{AB \times CB} = \frac{FL}{AF \times CF}$;

4110. and $\frac{BG^2}{AB^2 \times CB^2} = \frac{FL^2}{AF^2 \times CF^2}$.

4111. We ſuppoſe the little Arches bm, fn deſcribed with the Center A, and we have four ſimilar Triangles DCB, ECF, mBb, and nFf. They are all rectangular, and the greater are ſimilar becauſe of the correſpondent Chords BP, FQ; for the ſame Cauſe the Angles mBb and nFf are equal, and the leſſer Triangles are ſimilar: Likewiſe each ſmaller is ſimilar to it's greater; for, becauſe of the right Angle CBb, the Angles CBD, bBm taken together are equal to a right one; to a right one

* 32 El. 1. likewiſe is equal the Sum of the Angles CBD, BCD *, therefore the Angles bBm and BCD are equal.

4112. Theſe Things being ſuppoſed, the Ratio of Bb to Ff, which is the ſame as the Ratio of bm to fn, will be compounded of the following,

bm, Dd :: AB, AD;

* 4109. Dd, Ee :: CD, CE :: BG × AF, AB × FL *;

Ee, fn :: AE, AF

Therefore bm, fn :: Bb, Ff :: AB × BG × AF × AE, AD × AB × FL × AF :: BG × AE, AD × FL and

4113. Bb × AD × FL = Ff × BG × AE

* 4110. Now if we multiply this Æquation by the foregoing *, the firſt Member by the firſt Member, and the ſecond by the ſecond, and divide both the Members of this new Æquation by BG × FL × AC, we ſhall have what was to be demonſtrated, namely

$$\frac{B b \times BG \times AD}{AB^2 \times BC^2 \times AC} = \frac{F f \times FL \times AE}{AF^2 \times CF^2 \times AC^2}.$$

It

It is plain by a like Demonſtration, that two oppoſite Rings, whoſe Breadths are P*p*, Q*q*, do alſo equally attract the Particle A; which might be demonſtrated another Way; for Rings made at the ſame Time in the ſame Sphere, as B*b*, P*p*, act alſo equally on the Particle A. 4114.

Having drawn many Lines as AP, or rather multiplying their Number infinitely, a whole Sphere HPN, may be divided into Rings by the Revolution of thoſe Lines; then if we conceive a ſecond Sphere to be divided into an equal Number of Rings by the Revolution of ſuch Lines as AQ, which every one cut off an Arc ſimilar to that, which a correſpondent Line cuts off in a greater Sphere; each Ring in the leaſt Sphere will act equally with it's Correſpondent in the greater. 4115.

Whence it follows, that the whole Action of a ſmaller Sphere agrees with the whole Action of a greater; and this Action is the ſame however the Sphere be diminiſhed, if the Quantity of Matter remains; therefore the *Matter acts as if it was condenſed into the Center.* 4116. 4117.

The ſame Thing will happen, *if the Sphere be ſolid, and of the ſame Denſity every where, at the ſame Diſtance from the Center.* For ſuch a Sphere may be taken for a Congeries of hollow and concentrick Spheres, and like thoſe that we have treated of.

The Propoſition of N° 4082 being demonſtrated, we paſs on to the Demonſtration of 4088. We ſuppoſe the Particle A in the hollow Sphere, made of homogeneous Matter, and every where of the ſame Thickneſs, to be ſhut up and put into a Place. 4118. Pl. 126. Fig. 4.

Let us ſuppoſe two oppoſite Pyramids in the Vertex B A*b*, A F*f*. The Triangles A B*b* and A F*f* are ſimilar *, and AB or A*b*, is to A*f* or A F, (for we ſuppoſe that the Lines B F, *bf* contain an Angle infinitely ſmall) as B*b* to F*f*: for from that Similitude of the Triangles it follows that the Pyramids are equally inclined to their Baſes, and therefore that the Baſes are ſimilar, and to one another in a duplicate Ratio of the Lines B*b*, F*f* *, or AB, AF; but theſe Baſes are alſo as the Quantities of Matter in them; therefore the Particle A is drawn to the oppoſite Parts by Actions, which are directly in a duplicate Ratio of the Lines AB, AF *, and inverſely in the ſame Ratio; ſo that the oppoſite Forces are equal, and mutually deſtroy one another; therefore as the whole Surface of a Sphere may be divided into the Baſes of oppoſite Pyramids, which will all have A for their common Vertex, it follows that all the oppoſite Actions of a Sphere deſtroy one another mutually, and that a Particle of Matter may be at reſt in any Part of ſuch a Sphere.

* 35 El. 3. 6 El. 6.

* 20 El. 6.

* 4048. 4049.

CHAP. XII.

Of the Celeſtial Matter; where a Vacuum is proved.

4119. HAVING explained the Laws whereby the whole planetary Syſtem is governed, ſeveral Things muſt be firſt laid down before we proceed to the phyſical Explication of the Syſtem. We muſt begin by ſaying ſomething of the Celeſtial Matter, that is of the Medium in which the Bodies that make up the Syſtem are moved, which would be done in few Words, if all Philoſophers agreed that there is a *Vacuum*.

* 22. We have before proved that a *Vacuum* is poſſible *; now we are to demonſtrate that there is really one.

4120. *From only conſidering Motion we can deduce a Vacuum*; and this is a very common and uſual Way of proving it; to ſee the Force of which Argument, we muſt conſider, that indeed all Motions are not impoſſible without a Vacuum, but moſt of thoſe which are daily obſerved; which might be fully evinced by a longer Diſcuſſion; But it ſeems to me to be ſo evident from the following Conſideration, that it would be uſeleſs to add much more.

4121. The Figure of the leaſt Particles is unchangeable; for the Particle, whoſe Figure may be changed, conſiſts of ſmaller Particles, which are moved in reſpect to each other; and therefore if it has a changeable Figure, it is not one of the leaſt Parts.

4122. But if the Figure of theſe Particles be unchangeable, and a Body can move between them without ſuch a Separation of the Particles as to leave a void Space, this will depend on the Figure of the Particles, and the Relation which they have to one another, which a Mathematician will not deny. Therefore, if keeping Things in this State (as to their Figure and Relation) the Particles are increaſed, even in that Caſe Bodies may be moved without a *Vacuum*.

4123. Now ſuppoſing the ſmalleſt Particles increaſed to the Bigneſs of a Cubic Foot, whatever be their Figure and Relation with the other Parts, which we ſuppoſe increaſed in the ſame Proportion as the firſt; let any one conſider, whether Bodies of any Bigneſs can be carried between thoſe Parts in right Lines, and in all Sorts of Curves, and yet never ſeparate the Particles ſo as to leave Vacuities between them.

We

We cannot conceive how the moſt ſubtile Parts are made, and therefore often attribute to them ſuch Properties as do not follow from their Figure; but theſe Errors will be corrected, by imagining the Particles increaſed.

We alſo *prove a* Vacuum *by an Argument taken from Reſiſtance.* 4124.

We have ſaid that Matter is inactive *; ſome diſpute about the Word, but no Man denies the Thing; whence it follows that a Body cannot move through a Fluid, without undergoing a Reſiſtance *, and conſequently Retardation †. The Reſiſtance ariſing from the Inertia of the Matter (which Reſiſtance alone is here conſidered) depends upon the Quantity of Matter to be removed out of it's Place, which is the ſame whether the Parts of a Fluid be greater or leſs, if the Celerity of the Body remains the ſame: Whence it follows, that in determining what relates to the Reſiſtance, we muſt have no Regard to the Subtilty of the Fluid, as long as it cannot go through the Pores of Bodies; for if we come to ſuch a Fineneſs of Parts, that a Fluid ſhall partly penetrate a Body, it will leſs reſiſt the Body. 4125. * 19. * 1885. † 1953.

Now let us ſuppoſe any Ball or ſpheric Body to be moved along in a Medium of the ſame Denſity as itſelf, and ſo cloſe, that the Parts of the Medium cannot paſs through the Pores of the Body; this Body will be retarded every Moment, ſo that it's Velocity at laſt will be reduced to half; as may be proved by a Mathematical Demonſtration) before the Body has gone through the Length of it's Diameter and the half of it *. 4126. * 1974.

In Order to apply this Propoſition to a Motion in a very ſubtile Fluid, which freely penetrates the Pores of all Bodies, and fills all Places, we muſt conceive a ſpherical Body without any Pores at all; and that ſuch a Body may be ſuppoſed by imagining all the Particles of Matter cloſely joined, no Body will deny. 4127.

That the Reſiſtance of ſuch a Body in any Fluid does not depend upon the Bigneſs of the Parts of the Fluid, and is the ſame whether the Parts of the Fluid be equal, or any how unequal, is evident *. * 4125.

If every Thing be full of Matter, this Body can only move through a Fluid of the ſame Denſity as itſelf; for it muſt run againſt all the Matter which is in thoſe Places through which it paſſes, and in them the Matter is without Interſtices as it is in the Body; therefore it will loſe half it's Velocity, before it has run through the Length of it's Diameter and an half.

4128. Now let us ſuppoſe the Body to be increaſed, the Quantity of Matter remaining the ſame, and the Body continuing homogeneous; that is, let there be Pores in the Body, through which the moſt ſubtile Particles of Matter may paſs very freely; and let theſe Pores be equally diſperſed all over the Body. If the Body, thus changed, be moved, the very ſubtile Fluid, of which we ſpeak, will not run againſt the whole Surface, but only thoſe Parts of the Surface which are between the Pores, which Parts being taken together, becauſe we ſuppoſe the Body homogeneous, are equal to the Surface of the Body in the firſt Suppoſition, when we conceived it to be without Pores; for the Body being increaſed, the Surface has not been changed but only dilated by the Interpoſition of Pores: So that in both Caſes the Body will undergo the ſame Reſiſtance from the Impulſe upon the Surface; and the Reſiſtance on the dilated Body is greater from the Fluid running againſt the internal Parts of the Body. Wherefore this Body will ſooner loſe half it's Motion in the ſecond, than in the firſt Caſe; that is, before it has run through the Length of one Diameter and an half of the firſt ſuppoſed Bigneſs; and therefore it loſes a greater Quantity of Motion, in going through one and an half Diameters of the Bigneſs ſuppoſed in the ſecond Caſe.

4129. But this is contrary to Experience; for a homogeneous Ball of Gold, or Lead, *&c.* is much leſs retarded than what we have mentioned, in Water or Air; whence it follows, that the Suppoſition, that all Things are full of Matter, is falſe. Therefore there is a *Vacuum.*

4130. *That there is a* Vacuum *does* alſo *agree with the Phænomena relating to Gravity*; by which it follows that it is proportional to the Quantity of Matter. If all was full of Matter, Gravity would act equally every Way, and the Forces which are directed towards oppoſite Parts would deſtroy one another; and therefore no ſenſible Gravity would be obſerved: This Conſideration confirms that there is a Vacuum, and illuſtrates the Aſſertion; but is not alone ſufficient to prove it.

Theſe Things being premiſed, we muſt return to the Celeſtial Matter.

The Motions of the heavenly Bodies do not depend upon the
* 4099. Motion of the Celeſtial Matter if there be ſuch a Matter *; *where-*
4131. *by is overthrown the Opinion of thoſe which ſay that the heavenly Bodies are carried along by the common Motion of the Matter which fills our Syſtem.*

This

This Opinion is alſo overthrown by the Motion of the Comets; 4132.
if there was a Medium in the Syſtem which carried about the Planets in it's Motion, and alſo the Comets, it would at leaſt ſenſibly diſturb theſe laſt in their Motions, whilſt they come almoſt directly towards the Sun, or directly recede from it, or are carried in *Antecedentia*; that is, in a Motion contrary to the Motion of that Matter: Now as this Motion is not diſturbed, but follows the Way which depends upon Gravity, as it is obſerved, it is plain, that if there be any Celeſtial Matter, and that is in Motion, it does not exert a ſenſible Action on the Bodies of the planetary Syſtem, which is alſo deduced from the ſmall Reſiſtance of ſuch a Medium; for *by comparing the moſt ancient Obſervations with the modern, it* 4133.
does not appear that the Planets are ſenſibly retarded in their Motions. Yet in Air the Reſiſtance is ſenſible; wherefore the Denſity of the Medium in which the Planets ſhould move, muſt be almoſt immenſly leſs; Therefore *the planetary Syſtem is not filled, unleſs* it be 4134.
by ſuch *a very ſubtile Medium.*

But we may from the Diviſibility of Matter deduce, that a Quantity of Matter, how ſmall ſoever it be, may be diſperſed all over the planetary Syſtem, leaving but very ſmall Interſtices *. * 37.

CHAP. XIII.

Concerning the Motion of the Earth.

BESIDES the Queſtion that has been handled in the foregoing Chapter, there is alſo another to be examined, before we proceed to the Explication of the whole Syſtem. 4135.

That no Doubt may be made concerning the Syſtem, which has been explained in the firſt Chapter of this Book, we muſt here prove the Motion of the Earth concerning which it is no Wonder that many have doubted; for the Celeſtial Motions cannot be determined by us but by Obſervations made by Obſervers on the Earth; and the ſame Phænomena appear whether the Bodies themſelves be moved, or the Spectator be moved *; ſo that it is not to be proved * 3776.
by immediate Obſervations, whether the Motion of the Earth is to be referred to the heavenly Bodies or not.

That the Earth is carried about the Sun, is deduced from the Analogy 4136.
of the Motions, and from an Examen *of the Laws of Nature.*

4137. As to what relates to the Analogy of the Motions, it is to be obſerved, that Satellites revolve about *Jupiter* and *Saturn*, which are leſs than the central Body; that the Moon revolves about the Earth, than which it is leſs; *laſtly*, That the Sun has revolving about it leſs Bodies than itſelf, as *Mercury*, *Venus*, *Mars*, *Jupiter*, and
4138. *Saturn*: Now if the Earth revolves with the reſt, then every where *in our Syſtem the leſſer Bodies move about the greater*; now *there would be an Exception in the Rule in reſpect of the Sun, if that* vaſt
* 3748. Body *was to go round ſo ſmall a Body as the Earth* *.

About the Sun, *Jupiter* and *Saturn*, about which ſeveral *Bodies*
4139. revolve, thoſe *move the ſloweſt which are moſt diſtant from the central Body*, and according to this Rule, that the Squares of the periodical Times follow the Ratio of the Cubes of the Diſtances *; *which Rule* may be applied to the Earth, if it be carried about the Sun with the reſt of the Planets, as appears, if it's periodical Time, (namely the Time in which the Sun appears to perform an intire Revolution) and it's Diſtance from the Sun be compared with the Diſtances and periodical Times of the reſt of the Planets.

Now the Rule *has only one Exception if the Sun be moved about, and the Earth is at reſt.*

4140. In this Caſe *Mercury*, *Venus*, *Mars*, *Jupiter*, and *Saturn*, are ſubject to this Rule in their Motions, as alſo the five Satellites of *Saturn* and the four Planets that accompany *Jupiter*; only the Moon and the Sun would move the Earth in a Proportion quite different; and then the Celerity of the Sun would not only be greater than is required by this Law, but it's Velocity would at leaſt be ſix and twenty Times greater than that of the Moon, though it be removed to a vaſt Diſtance from the Earth, in reſpect to the Moon's Diſtance: And therefore in this reſpect, the Analogy of the Celeſtial Motions would be diſturbed.

4141. To theſe Arguments I ſhall add others, whereby it will clearly appear, that the Motion of the Earth is a neceſſary Conſequence of the Laws of Nature, which are deduced from Phænomena.

* 4047. All Bodies gravitate towards one another *, therefore *the Sun* and
4142. Earth do; but the Motion, whereby theſe Bodies tend towards one another, is deduced from direct Obſervations. Whichſoever of theſe Bodies moves about the other, deſcribes Areas by Lines drawn to the Center of it proportional to the Times which is evident from Aſtronomical Obſervations; therefore the Body moved is retained in a Curve by a Force, which is directed towards the Center of the
* 586. other *. Now as Reaction is always equal to Action †, *unleſs the*
† 361. 365.

Laws of Nature, which obtain conſtantly every where, be wholly overturned, theſe two Bodies tend towards one another with Celerities that are inverſly as their Maſſes *. * 4092.

The Quantity of Matter in the Earth is next to nothing, in Compariſon to the Quantity of Matter in the Sun, as we ſhall ſhew in the following Chapter; wherefore *the Sun muſt move very ſlowly whilſt the Earth comes towards it very ſwiftly.*

Whence it follows, that the Earth is carried about the Sun, leſt it ſhould fall upon the Sun by that very violent Motion whereby it is retained in it's Orbit *. 4143. * 561.

This Motion of the Earth is alſo deduced from the ſame Principles another Way. 4144.

Two Bodies that are carried towards one another by any Force, will at laſt concur, or continually recede from one another, unleſs each of them be ſo moved, as to have a centrifugal Force equal to the Force whereby it is carried towards the other Body; but as the Bodies which gravitate towards one another, tend towards each other with equal Preſſions *, *theſe Bodies cannot perſevere in their Motions about one another*, unleſs both of them be ſo moved as to have equal centrifugal Forces, which does not happen, unleſs they both revolve in equal Times about their common Center of Gravity; that is, if this Propoſition be applied to *the Sun and Earth, unleſs they both move about a Point, whoſe Diſtance from the Center of the Sun is to it's Diſtance from the Center of the Earth, as the Quantity of Matter in the Earth is to the Quantity of Matter in the Sun, they cannot perſevere in their Motions about one another* *. This Point or Center of Gravity muſt of Conſequence be very near to the Sun's Center. Now ſince whichſoever of theſe Bodies moves, it perſeveres in it's Motion about the other, it follows, that both of them are affected by the Motions abovementioned; and that the Sun is moved but a little whilſt the Earth deſcribes a very great Orbit. Whence it follows, that the Motion of the Earth cannot be denied by any one, who reaſons from the Laws of Motion that are deduced from Phænomena. * 361. 4145. * 611. 613.

Having proved *the* annual *Motion of the Earth*, and brought back the Earth amongſt the Planets, there remains but little Difficulty in Relation to the Motion of it *about it's Axis*; for no Body, that believes the annual Motion, doubts of this; a great many, which allow of the Motions about the Axis, deny the annual Motion; therefore it will be enough to obſerve by the by, that all the Planets, concerning which any Obſervations could be made in reſpect 4146. 4147.

ſpect of this Motion, do move about their Axes; and that the Earth has ſuch a Motion, *the uniform diurnal Motion in Bodies, at any Diſtances, does plainly enough ſhew.*

To which we muſt add, that the Celerity of the fixed Stars going through one Revolution in leſs than 24 Hours, can hardly be more probable than it is conceivable.

4148. This Motion is alſo diſagreeable to the Nature of all the heavenly Bodies; for, *if they are carried round*, they muſt every Day, with an equable Motion, deſcribe Circles that have the Earth for their Center; that is they muſt, by Lines drawn to the Center of the Earth, ſweep through Area's proportionable to the Times, and be retained in their Orbits by Forces which are directed towards the * 586. Center of the Earth *, and by which (by reaſon that Action and ‡ 561. Reaction ‡ are equal) the Earth muſt alſo be continually attracted towards *thoſe Bodies*; ſo that it *muſt neceſſarily be agitated by a very violent Motion*; whence it appears that the diurnal Motion muſt not be referred to the heavenly Bodies, but to the Rotation of the Earth about it's Axis.

4149. Thoſe, that obſtinately affirm that the Earth is at Reſt, object that Bodies, upon the Surface of the Earth, muſt (on account of their centrifugal Force) recede from the Earth along a Tangent to * 561. a Circle parallel to the Æquator *. We anſwer, that the Bodies in the Places, where they are, are carried round with the ſame Motion as the Surface of the Earth; and therefore, that, in reſpect of the Points of the Surface, they endeavour to recede in Lines per- * 579. pendicular to the Axis *; but alſo that Bodies by Gravity tend to † 4082. the Center of the Earth †; and therefore by a Motion compounded of both theſe, the Body is continually moved, or endeavours to * 318. 360. move *, but becauſe the firſt Motion is extremely ſmall in reſpect of the other, a heavy Body is turned but very little out of it's Direction towards the Center, and the Gravity is a little diminiſhed, ſo much the more as the Place is more diſtant from the Pole; which agrees with Experience. We ſhall hereafter ſhew, when we come to ſpeak of the Figure of the Earth, that the abovementioned Direction of heavy Bodies is every where directed perpendicularly to the Surface of the Earth; which is not exactly ſpherical.

4150. A Body which is thrown upwards, is acted upon, not only by the Motion wherewith it is thrown up; but it is alſo carried by the Motion that is impreſſed to the Perſon or Machine that impels the Body; that is, it is carried by the Motion which is common with the

the Surface of the Earth; and therefore the Body moves in the ſame Line (the Line being carried on with the Surface of the Earth) as it would do if the Earth was at reſt.

CHAP. XIV.

Concerning the Denſity of the Planets.

BEFORE we proceed to the phyſical Explanation of the Syſtem, we muſt determine the Quantities of Matter in ſome Bodies, and their Denſities; which being known, the Effects of the Laws, by which theſe Bodies are governed, will more eaſily appear. 4151.

The Quantities of Matter, in different Bodies, are to one another, as the Gravities at the ſame Diſtance from theſe Bodies *; which Gravities are to one another inverſly as the Squares of the periodical Times of the Bodies revolving about thoſe different Bodies at the ſame Diſtance *. By multiplying the Quantities which are in this Ratio, by the ſame Quantity, *(viz.)* by the Cube of this Diſtance, the Ratio of theſe Quantities will not be changed; which are therefore to one another as the Quotients of the Diviſions of the abovementioned Cube, by the Squares of the periodical Times aforeſaid: But the Quotient of ſuch a Diviſion is found for any Body, by dividing the Cube of the other Diſtance, let it be what it will, by the Square of the periodical Time of the Body revolving at that Diſtance; for ſuch Quotients are equal to one another, for all Bodies that revolve about the ſame Body at any Diſtances; as follows from the Equality of the Ratio between the Cubes of the Diſtances, and the Squares of the periodical Times at thoſe Diſtances*. From which we deduce, that *the Quantities of Matter, in any Bodies in our Syſtem, are to one another directly as the Cubes of the Diſtances at which other Bodies revolve about theſe, and inverſly as the Squares of the periodical Times of theſe revolving Bodies.* 4152. * 4048. * 616. * 3747. 4153.

Theſe Things are demonſtrated by ſetting aſide the Agitation of the central Body, whoſe Quantity of Matter is ſought 4154.

By reaſon of the Sun's Magnitude, in Reſpect of *Venus** (for ex.) which alone we conſider of the Planets, the Sun is ſcarce moved by the Action of that Planet *. And *Venus* may be conſidered as moving about a quieſcent Body. * 3748. * 4092.

• The Satellites of *Jupiter* and *Saturn* are indeed carried by the common Motion along with the primary Planets, but by reaſon of the Magnitude of the primary Planets, they are carried about them as about Bodies that are at Reſt.

4155. But the Moon acts ſenſibly enough upon the Earth and moves it; wherefore before we can compute the Motion of the Moon by
* 4153. the Help of the aforeſaid Rule *, in order to compare the Quantity of Matter in the Earth, with the Quantity of Matter in the Sun, *Jupiter* and *Saturn*, we muſt determine *the Diſtance at which*
4156. *the Moon would move about the Earth*, if it was at Reſt, (that is, *not carried about by the Action of the Moon,) in the ſame periodical Time in which it now performs it's Revolution.* Here alſo we don't take Notice of the Motion that is common to the Earth and Moon, by which they are both carried about the Sun.

4157. The Moon perſeveres in it's Motion about the Earth; therefore the Earth and Moon are moved about a common Center of Gravity; as follows from what has been demonſtrated concerning
* 4145. the Earth and the Sun *, and the Moon (with that Force with which it tends towards the Earth) revolves in an Orbit whoſe Semidiameter is the Diſtance of the Moon from the aforeſaid common Center of Gravity of the Moon and the Earth.

If the Earth was at Reſt, and the Moon continued at it's Diſtance from it, the Moon would move in a greater Orbit, and it's periodical Time would be greater; but the Moon being brought ſo much nearer as to have it's Center at *ſixty Semidiameters* Diſtance from the Earth, the periodical Time would be the ſame as the Time of the Revolution about the abovementioned Center of Gravity, as we ſhall demonſtrate in the next Scholium.

Theſe Things being premiſed, we proceed to the Computation.

4158. The Diſtance of *Venus* from the Center of the Sun is 723, and
* 3728. it's periodical Time is 19414160″ *.

4159. The fourth Satellite of *Jupiter* is diſtant from the Center of *Jupiter*, 12,4775. ſuch Parts of which *Venus* is diſtant from the Sun
* 3744. 723. The periodical Time of this Satellite is 1441929″ *.

4160. The fourth Satellite of *Saturn* is diſtant from the Center of *Saturn* 8,5107 of the ſame Parts, and it's periodical Time is
* 3745. 1377674″ *.

4161. Laſtly, the Diſtance of the Moon is 60 Semidiameters of the Earth from it's Center, and 3,054 of the aforeſaid Parts. It's
* 3743. mean periodical Time is 2360580″ *.

If

If you divide the Cubes of theſe Diſtances reſpectively by the Squares of their periodical Times, you will have in the Quotients, Numbers which are to one another as the Quantities of Matter in the aforeſaid Central Bodies *; which Quotients are to one another as the following Numbers: except the Earth concerning which we muſt have a Correction; becauſe, as we have already obſerved *, the Gravity of the Moon towards the Earth, is by the Sun's Action diminiſhed $\frac{10}{18066}$; therefore the Quantity of Matter diſcovered was to be increaſed in the Ratio of 17966 to 18066, which we have done. 4162. 4153. 4077.

Quantities of Matter.	*In the Sun.*	*In Jupiter.*	*In Saturn.*	*In the Earth.*	*In the Moon.*
	10000.	9,305.	3,250.	O,0512.	O,0013.

4163.

We have alſo the Proportion of the Diameters of theſe Bodies from Aſtronomical Obſervations, as follows. 4164.

Diameters.	*Of the Sun.*	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*
	10000.	997.	791.	109.

If the Quantities of Matter aboveſaid be divided by the Squares of the Diameters, the Quotients will be to one another as the Weights on the Surfaces of the aforeſaid Bodies *; and theſe Quotients are as the following Numbers. 4165. * 4083.

Gravities on the Surfaces.	*Of the Sun.*	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*	*Of the Moon.*
	1000.	936.	519.	431.	146.

4166.

If you divide theſe Numbers by the Diameters, you will have the Proportion of the Denſities of thoſe Bodies *. 4167. * 4087.

The Quotients, found by theſe Diviſions, are as the following Numbers.

Denſities.	*Of the Sun.*	*Of Jupiter.*	*Of Saturn.*	*Of the Earth.*	*Of the Moon.*
	10000.	9385.	6567.	39539.	48911.

4168.

We ſhall determine what relates to the Moon in the laſt Chapter, but we have added what we have done here, the better to compare it with the reſt. 4169.

It is not probable that the aforeſaid Bodies are homogeneous, from whence it follows, that the Denſities cannot be exactly determined, wherefore *we only determine the mean Denſities, that is, which the Bodies would have if the ſame Bodies keeping the ſame Quantity of Matter and Bulk which they now have, ſhould become homogeneous.* 4170. 4171.

*The abovementioned Proportion * between the Denſities in reſpect of all the Bodies, and the reſt of the Computations in reſpect of the Sun, Jupiter, and Saturn, are free from any ſenſible Error; when they are compared with the Earth, there may be ſome Error,* which muſt be corrected by Obſervations to be made hereafter, by which the Di- 4172. * 4168.

ſtance of the Earth from the Sun will be more accurately determined.

4173. Suppoſe the Diſtance of the Moon (which is 60 Semidiameters of the Earth) to be 3,054 ſuch Parts, of which *Venus* is diſtant
* 4161. from the Sun 723 *, that is, of which the Earth is diſtant from
† 3728.3729. the Sun 1000 †; which Diſtance of the Moon is diſcovered by ſuppoſing the Horizontal Parallax of the Sun 10″, 30‴, which cannot be looked upon as abſolutely true, although it be deduced from the moſt exact Obſervations that have hitherto been made, of the Parallax of *Mars*, when it is neareſt of all to the Earth, which
* 3925. is too ſmall to leave us without Suſpicion of ſome Miſtake *.

4174. But the Error in not determining truly the Proportion between the Semidiameter of the Earth and the Diſtance from the Sun, does not change the determined Denſity of the Earth, as is deduced
* 4162.4166. 4167. from Computations made about it *.

4175. For it follows from theſe, that the Denſities of Bodies are to one another in a Ratio compounded of the direct Ratio of the Cubes of the Diſtances of the Bodies carried about, and the inverſe Ratio of the Squares of the periodical Times of theſe revolving
* 4162. Bodies*; as alſo of the inverſe Ratio of the Cubes of the Diameters
† 4165.4167. of the central Bodies whoſe Denſities are required †; the Ratio compounded of theſe is compounded of the direct Ratio of a Fraction whoſe Numerator is the Cube of the Diſtance of the revolving Body, and whoſe Denominator is the Cube of the Diameter of the central Body, and the inverſe Ratio of the Square of the periodical Time of the Body carried about.

4176. But you have ſuch a Fraction, if you know the Ratio between the Diameter of the central Body and the Diſtance of the revolving Body from that Center, although this Diſtance can be compared with no other; but this Ratio is given in reſpect of the Earth and Moon, as well as in reſpect of the other Bodies; wherefore alſo the Ratio of the Denſity of the Earth to the Denſities of the other Bodies is exactly diſcovered.

SCHOLIUM.

Of the Diſtance of the Moon, ſuppoſing the Earth immoveable.

4177. WE ſuppoſe the Things which are explained in N° 4157; let *l* be the Diſtance of the Moon from the common Center of Gravity of the Moon and Earth; *t* the Diſtance of the Earth from the ſaid Center.

Therefore

Therefore $l+t$ is the Diſtance of the Moon from the Earth, that is 60,5 Semidiameters of the Earth; for we conſider the mean Diſtance.

We muſt determine, if the Earth ſtood ſtill, that is was immoveable in it's Place, at what Diſtance the Moon muſt be removed, to perform it's Revolution about the Earth thus at reſt, in a Time equal to that in which it does now, together with the Earth, perform it's Revolution about the common Center of Gravity *. * 4106. 4178.

Let the Diſtance ſought be x; and we ſhall have this Proportion,

$$l, x :: x^2, \overline{l+t}^2.$$

For the Forces, by which the Moon is drawn, when the Diſtances from the Earth are $l+t$ and x, are to one another as x^2 to $\overline{l+t}^2$ *; and theſe Forces are as the Diſtances, at which the Bodies, which are retained by thoſe Forces, would perform their Revolutions in equal Times *: and thoſe Diſtances are as l and x. * 4049. * 607.

Therefore $x^3 = \overline{l+t}^2 \times l$; and $x^3 \times \overline{l+t} = \overline{l+t}^3 \times l$.

Whence we deduce $l+t, l :: \overline{l+t}^3, x^3$;

And $\sqrt[3]{\overline{l+t}}, \sqrt[3]{l} :: l+t, x$.

But $l+t$ is to l, as the Quantity of Matter in the Moon and Earth together, is to the Quantity of Matter in the Earth alone; which Quantities, as we ſhall ſee in what follows, are to one another as 40,31, and 39,31; the Cube Roots of which Numbers, are $60,5 = l+t$, to 60; to which therefore x is equal, as we ſaid in N° 4157.

CHAP. XV.

The phyſical Explanation of the whole planetary Syſtem.

IN the firſt Part of this Book we have ſhewn, what are the Motions of the Bodies in the planetary Syſtem; now we muſt explain how theſe Motions follow from the Laws of Nature *; that is, how theſe Bodies, being once put in Motion, perſevere in thoſe Motions which we obſerve. 4179. * 355. 357. 361. 4047. 4048. 4049.

Let us conceive the Sun and *Mercury* to be left to themſelves, and they will come together *; but if they be projected, they may revolve about a common Center of Gravity in equal Times, and deſcribe immoveable Elliptic Lines *, and perſevere in that Motion; for it is plain, by mathematical Demonſtration in that Caſe, that the Bodies will deſcribe Ellipſes about the common Center of Gravity, ſimilar to that which the one of them could deſcribe with the ſame Forces about the other if it was at Reſt: This Center, on 4180. * 4047. * 4145. 626. 4049.

* 3748. on Account of the Sun's Magnitude *, is very little distant from the Center of the Sun itself.

4181. Let us conceive besides *Venus* to be projected at a greater Distance from the Sun, it will a little disturb the Motion of *Mercury*, which also, by it's Action upon *Venus*, will turn it a little out of the Way, and both will draw the Sun, sometimes the same Way and sometimes different Ways; but they never come towards one an-
* 3727. 3728. other * so as to have their mutual Action sensible in respect of the Action by which the Sun draws those Bodies; wherefore all these Irregularities are insensible, as we shall shew more distinctly. Whence we conclude that these three Bodies tend towards a Point that is between them near the Sun, which therefore is very little distant from the common Center of Gravity of them all.

4182. If the Earth, *Mars*, and the other Planets be successively projected at different Distances from the Sun, the same Reasoning
4183. will hold good. Whence it follows, that *all the Planets are revolved about the common Center of Gravity of all the Bodies which compose the System*, which is but little distant from the Sun, and that the Planets do not sensibly disturb one another in their Mo-
4184. tions; wherefore *they all describe the same Line singly, which they would describe about the Sun, if every one of them was alone with the Sun in the planetary System*, that is, immoveable Ellipses: For it
* 4049. 626. is plain, that those will be described by the Force of Gravity *; and it is proved by mathematical Demonstration, that no other immoveable excentric Lines can be described by a central Force acting
* 637. equally at equal Distances *.

4185. It will also more plainly appear, that all the Planets tend to a Point near the Sun, if we consider that the Quantity of Matter in the Sun is a thousand times, and more, greater than the Quantity
* 4163. of Matter in *Jupiter*, which is far the greatest of all the Planets *.

4186. When all *the Planets move*, though they move *the Sun* but little, yet they do move it, and draw it differently according to their different Situation in respect of one another, whence there arises a small Motion in the Sun, which always depends upon the Motion already acquired, and the Change which happens in it from the Action abovementioned, which varies every Moment.

4187. *It is owing to this Agitation of the Sun, that the Planets disturb one another less in their elliptic Motions round the Sun, than if the Sun was at Rest in the Middle of the System.* If *Jupiter* (ex. gr.) was equally distant from *Mercury* and the Sun, it would attract both
* 4092. these Bodies to itself with an equal Celerity *, whence the Situation,

in

in reſpect of the Sun, is leſs changed than if the Sun was not agitated by this Motion, and *Mercury* only was attracted by *Jupiter*: According to the various Diſtances of *Mercury* and the Sun from *Jupiter*, the one or the other is more attracted, and there is always a leſs Change in their reſpective Situation when both are carried the ſame Way, than if (the Sun being at Reſt) *Mercury* only ſhould be carried towards *Jupiter*.

This Reaſoning may be applied to all the Actions of the Planets, that are more diſtant from the Sun, upon thoſe that are leſs diſtant. As to what relates to the Action of thoſe that are nearer, upon thoſe that are farther from the Sun, according to the different Situation they draw a Planet to the Sun, or drive it from the Sun, and in conſidering one whole reſpective Revolution, that is, the Motion from one Conjunction to another, the Diſturbance is leſs than if the Sun was immoveable. 4188.

The Magnitude of the Sun, compared with the reſt of the Bodies of our Syſtem, is the Reaſon (as appears by what has been already demonſtrated) *that the Planets diſturb one another but little*; but ſince the Magnitude is not infinite, theſe mutual Actions muſt not be wholly overlooked, and therefore it will not be unuſeful to make ſome Computations about them. 4189.

We have ſaid, that it appears by Aſtronomical Obſervations, that *Jupiter* alters the Way of *Saturn* when it is neareſt to it *; why this Diſturbance is more ſenſible than the reſt is deduced from the Law of Gravity. * 4062.

The Actions of *Jupiter* upon *Saturn* when it is neareſt to it, and of the Sun upon the ſame Planet, by which it is kept in it's Orbit, are to one another directly as the Quantities of Matter in *Jupiter* and the Sun *, (viz.) as 9,305 to 10000 †, and inverſly as the Squares of the Diſtances of *Jupiter* and the Sun from *Saturn*, that is directly as the Squares of the Numbers 954, 434; for the Diſtances of *Saturn* and *Jupiter* from the Sun are as 954 to 520 *; wherefore, *when Jupiter is neareſt to Saturn, the* Diſtances of *Saturn* from *Jupiter* and the Sun are in the ſaid Ratio. The Ratio compounded of the two aforeſaid Ratio's, is as 45 to 10000, or as 1 to 222; this *Action of Jupiter conſpires with the Gravity of Saturn towards the Sun, and* therefore *increaſes it* $\frac{1}{222}$ *Part*: Whence it is no Wonder that the Diſturbance is ſenſible. 4190. * 4048. † 4163. * 3731. 3732. 4191.

We don't here conſider the Force by which *Jupiter* attracts the Sun, for the Orbit of *Saturn* is not changed by it, and what we had 4192.

had to explain was why Aſtronomers obſerve *Saturn* to be turned out of the Way; yet by the Action of *Jupiter* upon the Sun, the Sun is brought nigher to *Saturn*, and the reſpective Situation of theſe Bodies is more diſturbed, than is diſcovered by Aſtronomical Obſervations. The Force with which *Jupiter* in the aforeſaid Poſition attracts the Sun, and with which therefore the Sun is attracted towards *Saturn*, is to the Force with which *Jupiter* attracts
* 4045. *Saturn* as 434 ſquared to 520 ſquared *, that is as 31 to 45, which Number expreſſes the Force with which *Saturn* tends towards *Jupiter*, when the Gravity of *Saturn* towards the Sun is expreſſed by 10000. If we collect into one Sum the Forces of *Jupiter*, by which it attracts *Saturn* and the Sun; the Force, by which, from the Interpoſition of *Jupiter*, theſe Bodies tend toward each other, will be to the Gravity of *Saturn* towards the Sun, as 76 to 10000; but this Gravity is to the Gravity of the Sun towards *Saturn*, as
* 4048 4163. 10000 to 3, 25 *, wherefore *the mutual Acceſs, or Approach of the*
4193. *Sun and* Saturn, *is to the Increaſe of this Approach by the Action of* Jupiter *interpoſed*, as 10067 to 76, or as 131 to 1.

This Diſturbance is remarkable, and far the greateſt of any that happens in the Motion of any of the primary Planets; this alſo obtains only in this one Caſe of the Conjunction; for when *Jupiter* recedes from *Saturn*, the Diſturbance of the Motion of *Saturn*, in a ſhort Time becomes inſenſible.

4194. In the ſame Poſition of *Jupiter*, when it is neareſt to *Saturn*, the Force of *Saturn*, although it be the greateſt of all in this Caſe, does not ſo ſenſibly alter the Way of *Jupiter* about the Sun. The Action of *Saturn* attracting *Jupiter*, is to it's Action by which
* 4040. it attracts the Sun, as 954 Square to 434 Square *, therefore it attracts *Jupiter* with greater Celerity; and ſince they are both attracted the ſame Way, the Difference of theſe Forces is the Force, with which (from the Action of *Saturn*) *Jupiter* and the Sun are
* 918. ſeparated from each other *; which is therefore to the Gravity of the Sun towards *Saturn*, as the Difference of thoſe Squares, to the laſt; that is nearly as 72 to 19; but this Gravity of the Sun towards *Saturn* is to the Gravity of *Jupiter* towards the Sun, as 3, 25 to
* 4048. 4163. 10000 *, and as 520 Square to 954 Square †, that is as 19 to
† 4049. 17509; therefore the diſturbing Force of *Saturn* is to the Gravity
4195. of *Jupiter* towards the Sun as 72 to 19509, or as 1 to 2703; therefore *by the greateſt Action of Saturn, the Gravity of Jupiter towards the Sun is diminiſhed by* $\frac{1}{2703}$ Part, which Diſturbance is inſenſible.

The

The other mutual Diſturbances of the Planets are much leſs, as will appear by determining that, which is the greateſt of them all, (viz.) that of *Mars* by *Jupiter*, which is diſcovered by the ſame ſort of Computation as the foregoing. 4196.

The Diſtances of *Jupiter* from *Mars*, and the Sun when *Mars* is between the Sun and *Jupiter* in the ſame Line, are as 3677 to 5201 *; wherefore the Forces with which *Jupiter* attracts theſe Bodies, are inverſely as the Squares of thoſe Numbers †, that is nearly as 2, to 1. the Difference of which Forces is equal to the laſt, that is to the Gravity of the Sun towards *Jupiter*. This Gravity of the Sun towards *Jupiter* is to the Gravity of *Mars* towards the Sun, as 9,305 to 10000 *, and inverſely as the Squares of the Diſtances of thoſe Planets from the Sun †, and this Ratio is compounded of 1 to 12512, in which Ratio therefore is the diſturbing Force of *Jupiter*, to the Gravity of *Mars* towards the Sun. Wherefore *the Gravity of Mars towards the Sun is only diminiſhed* $\frac{1}{12512}$ *by the Action of Jupiter when it is near it.* 4197. 4198.

* 3730. 3731. † 4049. * 4048. 4163. † 4049.

Although theſe Diſturbances, ariſing *from the Actions of the Planets upon each other*, be very ſmall, and although thoſe, which happen in a different Poſition of the Planets, do in ſome Meaſure compenſate each other; yet the Proportion in which the Force, which keeps the Planets in their Orbits decreaſes, is a little changed by theſe Actions, ſo that it does not decreaſe exactly in an inverſe Ratio of the Square of the Diſtance: therefore although the Orbits are at Reſt as to Senſe, *after a great many Revolutions, a ſmall Change is obſerved in the Situation of their Orbits* *. 4199.

* 630. 3696.

From all this it follows, that if we ſuppoſe the Planets at firſt once projected at the Diſtances from the Sun at which they are moved, they will by the Laws already explained perſevere in thoſe Motions; and the Excentricity of the Orbits depends upon the Celerity and Direction of the firſt Projection. But theſe Motions may be preſerved very long, by reaſon of the ſmall Reſiſtance of the celeſtial Matter. 4200.

It is alſo plain, why, by Lines drawn to the Center of the Sun, they deſcribe *Areas* proportionable to the Times; namely, becauſe all other Gravities in the Syſtem, are very ſmall in reſpect of the Gravity towards the Sun *; therefore by this Gravity alone, it is that the Planets are retained in their Orbits, whence follows this Proportion of the *Areas* †. 4201.

* 4184. † 585.

And alſo the Motion in elliptic Lines, which are carried on very ſlowly, follows from the Law of Gravity; for theſe Lines would 4202.

* 626, 4049. be immoveable, if the Planets gravitated only towards the Sun *; but this *ſlow* Motion of the Orbits is deduced from the Action of
‡ 4199. the Planets upon one another ‡.

4203. Now in reſpect to the Proportion which is obſerved between the Cubes of the Diſtances, and the Squares of the periodical Times, it
* 621. 4049. is alſo deduced from the Law of Gravity *; ſo that if we add to
† 4052. 4191. theſe what we have ſaid of the Deflection of *Saturn* †, nothing will remain to be explained in reſpect of the primary Planets.

4204. That *the Motion of Comets depends upon the Law of Gravity*, is alſo deduced from Obſervations; and in reſpect of them, as has been ſaid concerning the Planets, the Sun's Gravity prevails, and by that
* 3754. 586. Gravity they reflect from a rectilinear Courſe *; but that the Curvature of their Way depends upon the ſame Gravity, follows from this; that a Body, by that Gravity, will deſcribe an Eliipſe, or a
* 626. 628. Parabola, or an Hyperbola *; which Lines it appears that thoſe Comets have deſcribed, whoſe Trajectories have been determined.

4205. *The Satellites of Jupiter and Saturn are moved by the ſame Laws*
* 3712. 3739. *about their Primaries, as the Primaries are moved about the Sun* *;
3747. wherefore the Explication of thoſe Motions ‡ may be alſo referred
‡ 4200. to them; for in theſe three Caſes, ſmaller Bodies are revolving at different Diſtances about a much greater Body: namely, Satellites about *Jupiter* and *Saturn*, and primary Planets about the Sun.

4206. *Whilſt ſecondary Planets are moved about a primary one, it is evident that they may all be moved with one common Motion*, whereby the reſpective Motions with which they are moved, in reſpect of each other, will not be diſturbed, becauſe a Body may at the ſame
* 359. Time be moved by different Impreſſions *: The Motion that a primary Planet has in common with it's Satellites, is the Motion of a primary Planet about the Sun.

4207. *Yet the Motion of the Secondaries is diſturbed by the Action of the Sun*, towards which they are carried ſometimes faſter, and ſometimes ſlower, according to the different Poſition of the Primary; and they alſo often concur towards the Sun's Center in different Directions. Theſe Irregularities, which are very ſmall, cannot be obſerved in the Satellites of *Jupiter* and *Saturn*, though they be really like thoſe which are obſerved in the Motion of the Moon; the leaſt Deviation of this laſt is very ſenſible to us. But that the Irregularities of the Moon exactly follow from the Theory of Gravity, will appear in the next Chapter.

SCHO-

SCHOLIUM.

Concerning Bodies revolving about a common Center of Gravity.

LET there be two Bodies of any Bigneſs attracting one another in the Ratio of the Quantity of Matter in them; let thoſe Bodies be placed at *a* and *b*, let *b* be kept back, and *a* be projected along *a d*, which when it is drawn from *b* deſcribes a Curve, of which *a e* is a very ſmall Part: Whilſt the Body by the projectile Motion runs through *a d*, it does by the Motion cauſed by Gravity go through *d e* parallel to *a b*. 4208. Pl. 126. F. 5. * 4048.

Let us ſuppoſe the ſame Bodies to be moved aſunder to the ſame Diſtance as in the foregoing Caſe, and to be placed in A and B; and therefore that *a b* and A B are equal.

Let the common Center of Gravity of the Bodies be C; and let them be both projected in the Parallels A D, B F, with Velocities that are to one another as the Diſtances from the Center of Gravity A C, B C, ſo that the Bodies may whirl about the ſame Center.

Let us ſuppoſe beſides that the Angles D A C, C B F are equal to the Angle *d a b*; and that the Velocities along *a d* are to the Velocities along A D and B F, as *a b* is to A C and B C, ſo that *a d*, A D, and B F are run through in equal Times, ſuppoſing them to be to each other as *a b*, A C, C B. By Gravity they come to each other in that Time through the little Space *d e*, which is run through by one Body alone *a* when *b* is kept back; but when both are left to themſelves, that little Space is ſo deſcribed by both, that $DE + GF = de$, in the ſame Manner that $AC + CB = ab$. Beſides D E, is to F G, as A C is to C B *; therefore *d e*, D E, F G, are to one another, as *a b*, A C, C B; but as *d e* is parallel to *a b*, and D E, as alſo G F, are parallel to A B, the Triangles *a d e*, A D E, B F G are ſimilar; as alſo *a e b*, A E C, B G C, and the Changes of Velocities are alſo alike.

This happens in the firſt Moment of thoſe Motions; and the ſame Things happen in the following Moments, and the Triangles, whoſe Baſes are run through in correſpondent Times in the three Figures, are always ſimilar; and as theſe whole Figures are made up of theſe Triangles, reſpectively ſimilar, they are alſo ſimilar, and run through in equal Times, as we have ſaid in N° 4180. 4209.

CHAP. XVI.

The phyſical Explication of the Moon's Motion.

4210. IT is certain that the Moon and Earth having once a projectile Motion given them, they can perſevere in their Motion about
* 4180. their common Center of Gravity *; if they be carried any Way by a common Impreſſion directed in parallel Lines, as was ſaid of
* 4206. the Satellites of *Jupiter* and *Saturn**, this Motion will not diſturb the Motion about the common Center of Gravity, which will follow that Direction only, becauſe in reſpect of the two Bodies it is at Reſt. But the Bodies are carried by a Motion compounded of that Impreſſion, and of the Motion about the common Center of Gravity, which will follow that Direction only, becauſe in reſpect of the two Bodies it is at Reſt. But the Bodies are carried by a Motion compounded of that Impreſſion and of the Motion about
* 360. the common Center of Gravity *; that is, they are whirled about that Center as it is carried along, as before it's Motion when it was at Reſt. If every Moment new Impreſſions common to both the Bodies act upon them, the Way of the Center of Gravity may be changed every Moment, which Change will be like that which the Bodies themſelves would undergo, if they had no reſpective Motion.

4211. Hence we deduce, that if whilſt the Moon and Earth are whirled round their common Center of Gravity, they be both projected, the Way of the Center of Gravity, by the Action of the Sun acting upon both Bodies, is the ſame as a Body projected in the ſame Manner, would deſcribe about the Sun.

4212. Whence it follows, that *the Moon diſturbs the Motion of the Earth, and* that *the common Center of Gravity of thoſe Bodies deſcribes that Orbit about the Sun which we have hitherto ſaid that the Earth deſcribed*; becauſe we hitherto overlooked the Action of the
4213. Moon; but *the Earth deſcribes an irregular Curve.*

4214. Let the Sun be at S; and the common Center of Gravity of the
Pl. 126. Moon Q, and the Earth M, at the Time of the full Moon, be
Fig. 46. at F: After one whole Lunation, that is, the next full Moon, let that Center be at A; and let F D A be the Orbit which we call that of the Earth; but in which the Center of Gravity abovementioned does really move.

If

If this Lunation be divided into four equal Parts after the firſt, the Center of Gravity will be at E, the Moon at P, and the Earth at L; after the ſecond Part of the Time, at new Moon, the Center of Gravity will be at D, the Moon at R, and the Earth at I; in the following Quadrature, the Center of Gravity will be at B, the Moon at O, and the Earth at H; laſtly at full Moon the Center of Gravity being at A, the Moon will be at N, the Earth at G: all which follows from the Revolution of the Earth and Moon about their common Center of Gravity, whilſt it is carried in the Orbit about the Sun.

Therefore we ſee the Earth moves in the Curve M L I H G, 4215.
which is twice inflected in each Lunation; which Curve alſo does not return into itſelf, becauſe the Inflections in the ſeveral Revolutions about the Sun do not coincide; for 12 Lunations, and a third Part of another, are performed every Year.

This Irregularity of the Motion of the Earth, which is deduced 4216.
from the Laws of Nature, *is too ſmall to become ſenſible in Aſtronomical Obſervations*; wherefore we may without any Error ſay, that the Center of the Earth itſelf deſcribes the Orbit F D A; for M F, or D I, the greateſt Diſtance of the Earth from that Orbit is about the 40th Part of the Diſtance M Q, which Diſtance itſelf is not the 300th Part of the Diſtance F S.

In explaining what relates to the Moon, we alſo neglect the Conſideration of the Motion of the Earth about the common Center of Gravity abovementioned, *but we ſuppoſe it to revolve at the Diſtance of* 60 *Semidiameters*, from the Center of the Earth; becauſe, as we 4217.
have before demonſtrated *, ſuch is the Diſtance at which in it's * 4157.
periodical Time, it could revolve about the Earth at Reſt, or carried along in an Orbit in which it ſhould not be diſturbed by the Moon's Action. By this Method, the Moon's Irregularities will be much more eaſily diſcovered; for they are the ſame; as is evident whether the Moon moves about the common Center of Gravity of the Moon and Earth, or about the Center of the Earth itſelf.

Let S be the Sun; T the Earth; and the Orbit of the Moon 4218.
A L B I; and laſt of all let the Moon be at A in the Quadrature; Plate 127.
it tends towards the Sun in the Direction A S, in the ſame Man- Fig. 1.
ner, and with the ſame Celerity that the Earth is carried towards S along T S, becauſe the Diſtances A S and T S are equal: This Celerity may be repreſented by T S or A S, the Action with which the Moon endeavours to deſcend along A S, and reſolved into two

Forces

Forces by drawing the Parallelogram ADST; ſo that the Moon will endeavour to move in the Directions AD and AT, the Celerities repreſented by thoſe Lines *.

* 360.

By the Preſſion which acts along AD, the Moon is carried with the ſame Celerity and the ſame Way as the Earth; by reaſon of the equal and parallel Lines TS and AD; wherefore by this Motion, the Relation between the Moon and Earth is not changed; but the Preſſion along AT conſpires with *the Gravity of the Moon towards the Earth*, and this Gravity *is increaſed by the Action of the Sun, when the Moon is in the Quadratures; and the Augmentation or Addition is to the Gravity of the Earth towards the Sun, as* AT *the Moon's Diſtance from the Earth is to* TS, *the Earth's Diſtance from the Sun.* That thoſe Preſſions along AT and TS are repreſented by thoſe very Lines, is plain from this, that the Gravities are Preſſions, which act on Bodies in Motion in the ſame Manner as on Bodies at Reſt *; and which therefore every Moment generate Augmentations of Velocities in the Ratio of the Gravities themſelves †; in which Ratio therefore are the Velocities produced in the ſame Time.

4219.

* 371.

† 4048. 133.

4220. TS *the Earth's Diſtance from the Sun remaining the ſame, the abovementioned Addition of Gravity increaſes and diminiſhes in the Ratio of the Line* AT, *the Diſtance of the Moon from the Earth.*

4221. But this Diſtance of the Moon from the Earth AT, if it remains the ſame and TS be increaſed, then AT would be leſs in reſpect of TS; therefore though there ſhould be no Change in the Force, whereby the Earth and Moon fall towards the Sun, the Addition would be leſs, and ſo much leſs as TS is greater, becauſe this, though increaſed, would ſtill repreſent the ſame Quantity; therefore the Addition will be inverſly as TS; but the Force of Gravity does not remain the ſame, when TS is increaſed, but is diminiſhed; wherefore alſo in that reſpect the abovementioned Addition is diminiſhed, and in the ſame Ratio with that Force of Gravity; therefore in the inverſe Ratio of the Square of the Diſtance TS *; if this Diminution be added to that abovementioned, we ſee that the *Addition* of which we ſpeak, *follows the inverſe Ratio of the Cube of the Diſtance of the Earth from the Sun.*

* 4049.

4222.

4223. *The Diſtance of the Earth from the Sun remaining the ſame, the Gravity of the Moon towards the Earth decreaſes more ſlowly in the Quadratures, than according to the inverſe Ratio of the Square of the Diſtance from the Center of the Earth*; for if the Addition in that Caſe ſhould follow the inverſe Ratio of the Square of the Diſtance,

as

as the Gravity from the Action of the Earth does*, this Ratio would not be diſturbed; but the Addition increaſes when the Gravity itſelf is diminiſhed; wherefore the Addition, when the Diſtance is increaſed, is always greater than is required, and conſequently the Diminution of Gravity is the leſs. * 4049.

This Addition is determined *in the mean Diſtances of the Moon from the Earth, and of the Earth from the Sun:* Let A T and T S be theſe mean Diſtances; *the Addition* required is to the Gravity of the Earth, towards the Sun, as A T to T S*; the Gravity of the Earth towards the Sun, *is to the Gravity of the Moon towards the Earth* (becauſe theſe Bodies are retained by theſe Gravities in their Orbits) directly as T S to T A, and *inverſly as the Square of the periodical Time of the Earth about the Sun, to that of the Moon about the Earth**: Therefore the Addition ſought is to the Gravity of the Moon towards the Earth, in a Ratio compounded of theſe Ratios; *that is* the abovementioned inverſe Ratio of the Squares of the periodical Times of the Earth and Moon, the other Ratios deſtroying one another. Theſe Times are given, and their Squares are inverſly *as* 1 *to* 178,73. 4224. * 4219. * 618. 4093.

Now if the Moon be at L, in which Situation the Sun attracts the Moon and Earth in the ſame Line, but not equally; the Moon it draws with a greater Force, becauſe it is leſs diſtant from it: The Difference of thoſe Forces is the Force by which the Moon is drawn back from the Earth, and by which the Gravity of the Moon towards the Earth is diminiſhed. 4225.

The Forces whereby the Moon at L, and the Earth at T, tend towards the Sun, are to one another as the Squares of the Lines S T and S L*: and the Difference of the Forces, that is, the diſturbing Force, is to the Force by which the Earth deſcends toward the Sun, as the Difference of thoſe Squares to the Square of the Line L S; that is, nearly as double L T to L S or T S; for theſe Lines do but very little differ from one another; and *the Difference of the Squares, whoſe Roots differ but little, is keeping the Proportion double that which is between the Roots.* * 4049. 4226.

If therefore T S, as before, repreſents the Force whereby the Earth deſcends towards the Sun, L *l* will repreſent the diſturbing Force and diminiſhing Gravity; when A T repreſents the diſturbing Force in the Quadratures*. Let the Moon be at *l*; it is again (together with the Earth) attracted by the Sun in the ſame Line; but the Earth, becauſe leſs diſtant, moves more ſwiftly towards the Sun; ſo that there is a Force which ſeparates the Earth from the Moon, 4227. * 4219. 4228.

Moon, namely, the Difference of the Forces which attract the
* 4225. Moon and the Earth *, which Force always acts contrary to the Gravity of the Moon towards the Earth, and diminiſhes it, in the ſame Manner as has been demonſtrated from the greater Gravity of the Moon towards the Sun, ſuppoſing it at L. At *l* alſo the ſeparating Force ſcarce differs from the ſeparating Force at L, for this Force, as we have ſhewn, is proportional to the Difference of the Squares of the Lines T S and L S; and that (as appears by ſuch another Demonſtration) proportional to the Difference of the Squares of the Lines *l* S, and T S; which Differences, by reaſon that L *l* is very ſmall in reſpect of T S, ſcarce differ among themſelves; ſo that the Force which diminiſhes the Moon's Gravity at *l*, is alſo repreſented by L *l*.

4229. Yet *the diſturbing Force is ſomething greater at the Conjunction* L, *than at the Oppoſition l*; for ſuppoſing the Differences between the Roots to be equal, the Squares keeping the Proportion, will differ ſo much the more, the leſs they are, and ſo keeping the Proportion, the Forces differ more at L and T, than at T and *l*, which alſo are
* 4049. leſs *.

4230. From this we conclude, that *the Force, which diminiſhes the Gravity of the Moon in the Syzygies, is double that which increaſes it in the Quadratures*; *namely*, *as* L *l* to A T. Wherefore in the Syzygies the Gravity of the Moon from the Action of the Sun is diminiſhed by a Part, which is to the whole Gravity, *as* 1 *to* 89,36; for in the Quadratures, the Addition of Gravity is to the Gravity,
* 4224. as 1 to 178,72 *.

4231. *In the Syzygies, the diſturbing Force* follows the ſame Proportion with half added to it; that is with the diſturbing Force in the Qua-
* 4230. dratures *; it *is* therefore *directly as the Diſtance of the Moon from*
† 4220. *the Earth* †, *and inverſly as the Cube of the Diſtance of the Earth*
‡ 4222. *from the Sun* ‡.

4232. *At the Syzygies, the Gravity of the Moon towards the Earth, receding from it's Center, is more diminiſhed than according to the inverſe Ratio of the Square of the Diſtance, from that Center*; for it would be diminiſhed in that Ratio, if the Force to be taken away followed the ſame Ratio; but on the contrary, as it increaſes when
* 4231. the Diſtance becomes greater *, the Diminution is always greater than in that Ratio, which is the inverſe of the Square of the Diſtance.

4233. Laſtly, let the Moon be at F, in any immediate Place between the Syzigy and Quadrature, it is drawn towards the Sun along F S, by

from which ſince it is leſs diſtant than the Earth T, it is attracted with more Force than the Earth: Let the Force with which the Moon tends to the Sun, be to the Force with which the Earth is carried towards it as F M to T S, which alſo before has been made uſe of to expreſs the ſame Gravity of the Earth. Draw the Parallelogram F H M I, whoſe Diagonal is F M, and whoſe Side F H is parallel and equal to the Line T S. The Gravity of the Moon towards the Sun is reſolved into two Forces, one along F H, the other along F I, and theſe Lines denote the Preſſures whereby the Moon endeavours to move along them *. The Action along F H * 360.
is common to the Moon and the Earth, which with an equal Force, and in a Line parallel to it, does alſo tend to the Sun; ſo that by this Motion of the Moon the Situation of it, in reſpect of the Earth, will not be changed, and the diſturbing Force will be only the Preſſure along F I.

By reaſon of the immenſe Diſtance of the Sun, the Part M S of 4234.
the Line M F is ſmall, in reſpect of the whole, and the Angle F S T, where it is the greateſt, as A S T, is hardly more than the 6th Part of a Degree; whence it follows, that the Lines M I and S N are very near one another, and that the Points I and N are ſcarce ſenſibly diſtant, and may without any ſenſible Error be confounded together; which Error, notwithſtanding how little ſoever it need be regarded, in Conſideration of one whole Revolution, is compenſated by a contrary Error when the Moon is at E. Therefore the diſturbing Force is expreſſed by F N.

It is to be obſerved, when only the Part E F *of the Line* E S *is conſidered, that is to be looked upon as parallel to the Line* L *l*, becauſe 4235.
of the ſmall Angle which theſe Lines make.

From the Point N draw N Q perpendicular to the Line F T, 4236.
continued if Need be, in which the Moon gravitates towards the Earth; and let the rectangular Parallelogram F P N Q be drawn; let us conceive the Force along F N reſolved into two others, acting in the Directions F Q and F P, and repreſented by theſe Lines *: By the Action along F Q, the Gravity is diminiſh- * 360.
ed, in the Caſe repreſented by this Figure; but it is increaſed when the Point Q falls between F and T; but by the Preſſion along F P the Moon in it's Orbit is drawn towards the next Syzygy L, and the Motion of the Moon is accelerated or retarded, according as this Force conſpires with, or acts contrary to, the Moon's Motion.

4237. Near a Syzygy, the Gravity of the Moon is diminiſhed, and the Line F Q, which follows the Proportion of this Diminution grows leſs, receding from the Syzygy till it vaniſhes, at the Diſtance of about 54 Deg. 44 Min. from it; at a greater Diſtance of the Moon from the Syzygy, Q falls in between F and T; and the Gravity of the Moon towards the Earth is increaſed by the Sun's Action.

4238. The Force along F P vaniſhes in the Syzygy L, receding from it, it increaſes quite to the Octant, which is the middle Point between the Syzygy and the Quadrature; and then it diminiſhes again till it vaniſhes quite at B.

4239. Between B and *l*, or *l* and A, the diſturbing Motions are determined in the ſame Manner, as in A L B, the oppoſite inferior Part of the Orbit; at E and F, the Diminution of Gravity is equal, and in that Poſition it is drawn in the Orbit with an equal Force towards the Syzygy *l*, with that with which at F it is impelled towards the Syzygy L.

4240. Hence it follows, *that in the Motion of the Moon from the Syzygy to the Quadrature*, between L and B, as alſo between *l* and A, *the Gravity of the Moon towards the Earth is continually increaſed, and the Moon is continually retarded in it's Motion.*

4241. But *in the Motion from the Quadrature to the Syzygy*, between B and *l*, as alſo between A and L, *every Moment the Moon's Gravity is diminiſhed, and it's Motion in it's Orbit is accelerated.*

4242. You may determine the Forces upon which theſe Effects depend, by comparing them with the known Force, whereby Gravity is
* 4224. increaſed in the Quadratures *, and which is repreſented by the Moon's Diſtance from the Center of the Earth.

4243. The Lines M I, H F, S T, are equal by Conſtruction; therefore when the Points I and N are confounded, M N is equal to S T, and M S is equal to N T. The Lines M F and S T repreſent the Forces, whereby the Moon at F and the Earth at T are carried towards the Sun S; therefore they are as the Square of the
* 4049. Line T S to the Square of the Line F S *; wherefore, as F G is the Difference of theſe Lines, F M and T S differ from one another
† 4226. double the Line G F †, and adding G F to the Line F M, the Difference between G M and T S, that is, M S will be triple the Line F G, and therefore this is alſo the Quantity of the Line
* 4235. N T: Now as F E is double F G *; therefore N T will be to F E as Three to Two.

Let

Let F T be continued, if Need be, and from E draw E V perpendicular to it; the Triangles E V F and N Q T, which are rectangular, will be ſimilar, by reaſon of the alternate Angles V F E and Q T N *: Therefore N T is to F E, that is, Three is to Two, as N Q, equal to F P is to E V; which therefore is proportional to two third Parts of the Force, which is expreſſed by F P; but E V is the Sine of the Angle E T V at the Center which is double the Angle E F V at the Circumference *, equal to the Angle F T L, which is the Diſtance of the Moon from the Syzygy. Therefore, 4244. * 4235. 29. El. I. * 20. El. III. 4245.

as the Radius T A or T E *is to a Sine and an half of double the Diſtance of the Moon from the Syzygy*, namely F P, *ſo the Addition of Gravity in the Quadratures* (which is expreſſed by the Radius T A) *is to the Force which accelerates or retards the Motion of the Moon in it's Orbit.*

The Computation of this Diminution of Gravity, and of it's Increaſe at a leſs Diſtance from the Quadratures, is deduced from the ſame Principles.

This Diminution is repreſented by the Line F Q, which is equal to Q T *minus* the Radius; but from the Conſideration of the Triangles abovementioned, V F, taken one and a half is equal to Q T; therefore V T and an half, with half the Radius added to it, expreſſes the required Diminution of Gravity; and *the Radius is to the Sum or Difference of one and a half the Co-ſine of double the Diſtance of the Moon from the Syzygy and half the Radius. As the Addition of Gravity in the Quadratures, to the Diminution or Increaſe of Gravity in that Situation of the Moon, concerning which the Computation is made.* 4246. 4247.

We make uſe of the Difference of the Co-ſine from half the Radius, when the Angle is ſuch whoſe Co-ſine is greater than a right Angle; becauſe in that Caſe we make uſe of the Co-ſine of the Complement of the Angle to two right Angles: When in this ſame Caſe the Co-ſine and a half, which we make uſe of, is greater than half the Radius, the Quantity found is to be added; that is, increaſes the Gravity; which obtains every where between the Quadrature, and 35 Deg. 16 Min. from it. 4248.

Theſe Forces, whatever is the Figure of the Moon's Orbit, are exactly determined; for they are compared with the Addition of Gravity in the Quadratures, ſuppoſing the Moon in the Quadrature to be at the ſame Diſtance from the Earth, at which it really is in the Place which is conſidered; but this Addition is diſcovered in every Caſe *. 4249. * 4224. 4222. 4220.

4250. Though it be foreign to the Purpoſe of this Work, to give a Computation of the Moon's Motion, I thought it neceſſary to explain in a few Words, what is the Method whereby to diſcover the Forces that govern the Moon; becauſe the more exactly we know the Forces, the more eaſily we ſhall conceive their general Effect.

4251. Now to examine the Moon's Motion, we muſt ſingly conſider it's ſeveral Irregularities; which to do without Confuſion, we muſt remove ſeveral Irregularities, and conceive the Moon as moving in a Circle about the Earth in which Curve it is plain, that it can be * 638. 4049. retained by Gravity *. We alſo conceive that the Orbit of the Moon is in the Plane of the Ecliptick.

4252. This Motion is diſturbed by the Action of the Sun, and *the Orbit is more convex in the Quadratures than in the Syzygies.* The Convexity of a Curve which a Body deſcribes by a central Force, is ſo much the greater as the central Force does more ſtrongly every Moment turn the Body out of the Way; it is alſo greater the more ſlowly the Body moves; becauſe the central Force, acting the longer, has a greater Effect in inflecting the Way of the Body. From contrary Cauſes the Convexity of the Curve is diminiſhed. Both concur in increaſing the Convexity of the Orbit in the Quadratures *, and diminiſhing it in the Syzygies †.

* 4240.
† 4241.

4253. From this it follows, that the circular Figure of the Moon's Orbit is changed into an Oval, whoſe greater Axis goes through the Quadratures; ſo that the more convex Parts are in the Quadra-

4254. tures. Wherefore *the Moon is leſs diſtant from the Earth at the Syzygies, and more at the Quadratures*, and it is no Wonder that the Moon comes towards the Earth in the Syzygies, when it's Gravity is diminiſhed; becauſe the Acceſs is not the immediate Effect of this Diminution, but of the Inflection of the Orbit towards the Quadratures.

The Motion of the Moon, taking away the Action of the Sun,

4255. is not in a Circle, but in an Ellipſe, one of whoſe Foci coincides

* 3740. 626. 4049. 636. with the Center of the Earth *; for the Orbit of the Moon is excentric, and it is retained in it by the Force of Gravity.

Therefore what has been demonſtrated cannot be exactly applied to the Moon's Motion; for as the Forces which generate the Deviations explained, do really act upon the Moon, the Ellipſe, which the Moon would deſcribe if the Sun was taken away, is changed,

4256. and *cæteris paribus, the Propoſitions of* N° 4252, 4254. *may be applied to the Moon's Motion.* That is, the Figure of the Ellipſe (which the Moon would deſcribe if the Sun was taken away, in

any

any Situation of the Sun) the Sun being preſent, is a little changed, the Parts, which are in the Quadrature, become more convex, when on the contrary thoſe that paſs through the Syzygies loſe of their Convexity; whence neceſſarily follow Variations in the Diſtances.

In the Quadratures and Syzygies, the diſturbing Force acts in the ſame Line as the Force of Gravity towards the Earth *; therefore the Force which continually acts upon the Moon, and retains it in it's Orbit, is directed towards the Center of the Earth, and *the Moon deſcribes Area's by Lines drawn to the Center of the Earth proportional to the Times* *. 4257. * 4210. 4225. 4228. * 585.

In other Points of the Orbit, as F beſides the Force which acts in the Line F T, there is alſo another, whoſe Direction is perpendicular to F T *, which is here repreſented by F P: the Direction of the Force compounded of both is directed by Degrees ſidewiſe to the Line F T, and does not tend to the Center of the Earth †; wherefore *the Areas by Lines drawn to the Center of the Earth are not exactly proportional to the Times* *. In the Octants, F P is the greateſt of all; and the Force which is repreſented by that Line is to the Gravity of the Moon towards the Earth, in that Point, in the mean Diſtances of the Sun and Moon, as 1 to 119, 15 *. Wherefore the Direction of the Force, compounded of the Actions of the Sun and Earth upon the Moon, makes an Angle of about half a Degree with the Line F T. 4258. Plate 127. Fig. 1. * 4236. † 318. * 586. * 4295.

The Motion of the Moon is ſubject to ſeveral other Irregularities; ſo that it deſcribes a Curve wholly irregular; which *Aſtromers*, in order to ſubject it to the moſt exact Computations that can be made, do *reduce to an Ellipſe which they conceive to be agitated by various Motions, and alſo to be changeable, leſt the Moon ſhould go out of it.* 4259. 4260.

In reſpect to central Forces we have obſerved, that a Body does not deſcribe an Ellipſe, if the central Force, by which it is retained in it's Orbit, decreaſes in any other Ratio than the inverſe Ratio of the Square of the Diſtance; but that the Curve may be often reduced to a moveable Ellipſe *, concerning which it is to be obſerved that the Ellipſe, in that Motion, turns about *one of it's Foci, and the Motion of the Ellipſe is directed ſometimes the ſame Way as the Motion of the Body* *; *and ſometimes the contrary Way.* 4261. * 636. * 631. 632.

Hence it follows, the Orbit of the Moon cannot be referred to an elliptic Orbit, unleſs you ſuppoſe it agitated by four Motions every Revolution; that is, unleſs the Line of the Apſides, which goes 4262.

goes through the Center of the Earth, goes forwards twice, and backwards twice.

4263. *The Apſides of the Moon go forward when the Moon is in the Syzygies* *, or rather whilſt the Moon moves between the Points, which are 54 Deg. 44 Min. diſtant from them †. *In the Quadratures*, and between the Points diſtant from them 35 Deg. 16 Min. *The Apſides go backwards*, that is move in *Antecedentia**.

* 631. 4232.
† 4247.
4264.
* 632. 4223. 4247.

4265. The Forces upon which the *Progreſs* and Regreſs *of the Apſides* depend, are the Forces which diſturb the Motion of the Moon, which have been before explained; therefore ſince the diſturbing Force in the Syzygies, is double the diſturbing Force, in the Quadratures *; the Progreſs, which alſo has Place in a longer Arc ‡, *conſidering one intire Revolution of the Moon, exceeds the Regreſs, cæteris paribus.*

* 4230.
‡ 4263.4264.

4266. In a Circle whoſe Center is in the Center of the Forces, the Diminution of the Force, in receding from the Center, produces no Effect; becauſe in ſuch a Line the Body does not recede from the Center; therefore the Effect of this Diminution is ſo much the greater, as the Curve deſcribed by the Body differs more from ſuch a Circle.

In an elliptic Orbit, one of whoſe Foci coincides with the Center of the Forces,

4267. the Curvature *in the Apſides* differs moſt of all from ſuch a Circle, and *the Effect of the Diminution of the Force, in receding from the Center of the Forces, is the greateſt of all.*

4268. *If this Orbit is but a little excentric at the Ends of the leſſer Axis*, the Curvature of the Circle above-mentioned differs little from the Curvature of the Ellipſe, in reſpect of the Forces, and *the Effect of the Diminution is the leaſt of all.*

4269. *The Progreſs and Regreſs of the Apſides* depend upon the Proportion, according to which the Force of Gravity decreaſes, receding from the Center of the Earth *; it *is* therefore *the Effect of the Diminution of the central Force.*

* 631. 632.

4270. This Motion of the Apſides, which we have explained, undergoes ſeveral Changes; *the Apſides go forward faſteſt of all in a Revolution of the Moon, ſuppoſing the Line of the Apſides in the Syzygies* *; *and in that very Caſe, they go back the ſloweſt of all in the ſame Revolution* ‡, becauſe, by reaſon of the ſmall Excentricity of the Moon, the Quadratures are but very little diſtant from the Ends of the leſſer Axis of the Orbit.

Plate 127. Fig. 2.
* 4263.4269. 4267.
‡ 4264.4269. 4268.

4271. *Suppoſing the Line of the Apſides to be in the Quadratures, the Apſides are carried in* Conſequentia, *the leaſt of all in the Syzygies* *; *but they return the ſwifteſt in the Quadratures* †; *and in this Caſe,*

Pl. 127. F. 3.
* 4263.4269. 4268.
† 4264.4269. 4267.

Caſe, in one intire Revolution of the Moon, the Regreſs exceeds the Progreſs.

Whilſt the Earth is carried along in it's Orbit, the Line of the Apſides does ſucceſſively go through all Situations in reſpect of the Sun; wherefore, *conſidering a great many Revolutions of the Moon taken together, the Apſides go forwards* *; and it is plain from Obſervations, that in the Space of about eight Years, the Line of the Apſides performs one intire Revolution. 4272. * 4265.

We have alſo ſaid that the Excentricity of the Orbit is not conſtant.

The Exentricity of a Body is increaſed, if the central Force, the Diminution being continued, *decreaſes faſter than before*, whilſt the Body is carried from the lower to the upper Apſis; for then it is every Moment leſs attracted, than if the Force decreaſed leſs, and therefore it recedes the more. The Excentricity of the Orbit is alſo thereby increaſed, in the ſame Caſe, in the Motion from the upper to the lower Apſis, becauſe in this Caſe, coming towards the Center, the Force increaſes ſo much the faſter, as the Body deſcends more towards the Center; ſo that in each Caſe, the Difference, between the greateſt and leaſt Diſtance from the Center of the Forces, may become greater, and the Excentricity be thereby increaſed. By the ſame Reaſoning it appears, that *the Excentricity is diminiſhed, when the central Force decreaſes more ſlowly than before in the Receſs from the Center.* 4273. 4274.

Applying this to the Moon's Motion, *it appears, that the Excentricity of the Orbit, every Revolution, undergoes various Changes:* That it is increaſed when the Moon goes through the Syzygies *, and diminiſhed when it is in the Quadratures †: *That Excentricity is the greateſt of all when the Line of the Apſides is in the Syzygies*; becauſe in one intire Revolution, the Cauſe which moves the Excentricity is the greateſt of all; and that which diminiſhes it, the leaſt of all, becauſe the Forces in the Apſides, being compared, do decreaſe faſter than in an inverſe Ratio of the Square of the Diſtance *, whence this Addition follows †, which prevails in this Poſition ‡: But *the Orbit is the leaſt excentric of all, when the Line of the Apſides is in the Quadratures*, the Diminution of the Excentricity prevailing *. 4275. * 4232. 4273. † 4223. 4274. 4276. * 4232. † 4273. ‡ 4267. * 4223. 4274.

We have ſaid that the Moon moves in a Plane inclined to the Plane of the Ecliptic; that the Line of the Nodes is carried round *in Antecedentia* *; and that the Inclination of the Orbit is not conſtant †; theſe Effects are alſo deduced from the Action of the Sun upon the Moon. 4277. * 3743. † 3742.

By

By reaſon of the ſmall Inclination of the Moon's Orbit, the Forces which we have hitherto conſidered acting in the Plane of the Ecliptic, not regarding the Inclination of the Orbit, may (without any ſenſible Error) be referred to the Plane of the Orbit; and
4278. the Moon in it is ſubject to the Motions before explained: But
* 4260. *there is a Force which removes the Moon from the Plane of the Orbit* *; ſo that we muſt conceive that Plane to be agitated, otherwiſe the Moon would go out of the Orbit.

4279. Let the Moon be at F; if we attend to what has been ſaid above
Plate 127. concerning the Action of the Sun *, it is plain, that the Plane of
Fig. 1. the Parallelogram F H M I goes through the Line T S, which joins
* 4233. the Centers of the Earth and Sun; and therefore it is in the Plane of the Ecliptic; ſo that the Point N, to which is directed the Force diſturbing F N, on account of the Action of the Sun, is in that Plane.

4280. Let the ſame Force be repreſented by F I; at F let F R be raiſed
Pl. 127. perpendicular to the Plane of the Orbit; and imagine the Paralle-
Fig. 4. logram F R I *i*, whoſe Side F *i* is in the Plane of the Orbit, and whoſe Diagonal is F I; the diſturbing Force along F I, is reſolved into two, in the Directions F R and F *i*, which theſe Lines repre-
* 360. ſent*, and of which this laſt acts in the Plane of the Orbit: So that we muſt refer to this what relates to the diſturbing Force, of which we have treated in N° 4233; for the Lines *F i* and F I ſcarce differ, and the Plane of the Parallelogram F R I *i* is perpendicular to the Plane of the Moon's Orbit.

4281. The Line F R muſt be determined, which repreſents the Force that acts perpendicular to the Plane of the Orbit, and removes the Moon from that Plane; now the Ratio of the Line F R or I *i*, to the Radius E T, is the Ratio of the diſturbing Force, which is
* 6337. ſpoken of here, to the Increaſe of Gravity in the Quadratures *.

4282. In the Caſe of this Figure, in which the Line of Nodes N *n* is in the Quadratures, we find out F R; becauſe I T, which is N T of *Fig.* 1. is given, and becauſe I T is to I *i*, or F R, as the Radius
* 4243. to the Sine of the Inclination of the Orbit *.

4283. But in every Caſe the Force muſt be determined which drives the Moon out of the Plane; let us therefore ſuppoſe the Line of Nodes carried to the Situation M *m*, whereby, every Thing elſe remaining as before I *i* is changed. To M *m* continued, if Need be let *i* X and I X be drawn perpendicular, which make an Angle equal to the Inclination of the Plane of the Orbit.

The

The Ratio between E T and I *i*, that is *the Ratio between the Addition of Gravity in the Quadratures, and the Force*, which we ſeek, *which removes the Moon out of the Plane of it's Orbit*, is compounded of the Ratios of the Line E T to T I, of the Line F I to I X, and laſtly of the Line I X to I *i*. The firſt is the Ratio between the Radius, and three Times the Sine of the Diſtance of the Moon from the Quadrature *; the ſecond is the Ratio of the Radius to the Sine of the Angle I T X, that is, of the Diſtance of the Node from the Syzygy; laſtly, the third is the Ratio of the Radius to the Sine of the Inclination of the Orbit: And the Ratio, compounded of theſe, *is the Ratio of the Cube of the Radius to three times the Product, of the Sines of the Diſtances of the Moon from the Quadrature, and of the Node from the Syzygy, as alſo of the Inclination of the Plane.* To this Force alſo is to be referred N° 4249. 4284. * 4243.

This Force vaniſhes in the Quadratures, becauſe the Point I coincides with the Point T, which is the Center of the Earth, and the Line I *i* vaniſhes; the Lines F I and F *i* concurring in the Plane of the Orbit, which alſo follows from the Computation abovementioned *; the Sine of the Diſtance of the Moon from the Quadrature vaniſhing, and conſequently, the whole Product which is multiplied by that Sine. 4285. * 4284.

That ſame Product vaniſhes alſo, and with it *the Force* which it repreſents, when the Sine of the Diſtance of the Node from the Syzygy *vaniſhes*, that is, *ſuppoſing the Line of the Nodes in the Syzygies:* It is alſo deduced from this, that the Line of Nodes N *n* continued, goes through the Sun; wherefore the Sun is in the Plane of the Orbit itſelf, and therefore cannot draw the Moon but in that Plane. 4286. Plate 127. Fig. 5.

The Force alſo *which we examine, is increaſed as the Moon advances towards the Syzygy, and as the Node recedes from it* *. 4287. * 4284.

Let P *p* be the Plane of the Ecliptic, P A the Orbit of the Moon; when the Moon is come to A, that is, is receded a little from the Node, it is removed out of the Plane of the Orbit, and in the ſecond Moment is not carried along A B, (the Continuation of the Orbit P A) but along A *b*; becauſe it comes towards the Plane of the Ecliptic along B *b*; therefore it is moved as if it came from a more diſtant Node *p*. Whence it appears, that *the Nodes go backward, whilſt the Moon moves in it's Orbit*, as long as it recedes from the Node: The Nodes alſo go back whilſt the Moon is going to the oppoſite Node; becauſe as the Moon is continually driven out of it's Orbit towards the Plane of the Ecliptick, it is continually 4288. Plate 127. Fig. 6. 4289.

directed to a Point leſs diſtant, and comes ſooner to the Node, than if, not being agitated by ſuch a Motion, it had continued in Motion with the ſame Celerity.

4290. *Conſidering one intire Revolution of the Moon*, cæteris paribus, *the Nodes move in* Antecedentia *ſwifteſt of all, when the Moon is in the*
* 4287. *Syzygies* *, *then ſlower and ſlower, till they are at Reſt when the Moon*
† 4285. *is in the Quadratures* †.

4291. Whilſt the Earth is carried round the Sun (even when we don't attend to the abovementioned Motion of the Nodes) *the Line of Nodes* does ſucceſſively acquire all poſſible Situations in reſpect of the Sun; and *every Year goes twice through the Syzygies, and twice through the Quadratures.*

4292. *If* now *we conſider ſeveral Revolutions of the Moon, the Nodes in one whole Revolution go back very faſt, the Nodes being in the Qua-*
* 4287. *dratures* *; *then ſlower, till they come to Reſt, when the Line of*
† 4286. *Nodes is in the Syzygies* †.

4293. By the ſame Force with which the Nodes are moved, *the Inclination of the Orbit* is alſo changed; it *is increaſed as the Moon recedes from the Node; and diminiſhed as it comes to the Node.*

4294. For the Angle *b p* L is leſs than the Angle A P L, and for the ſame Cauſe it is continually diminiſhed, and the Inclination becomes greater; but when the Moon is come to the greateſt Diſtance from the Plane of the Ecliptic, and is going towards the oppoſite Node, the Direction of the Moon is continually inflected towards the Plane of the Ecliptic, and leſs inclined to it than if it continued in Motion in it's Orbit: Let N n *n* be the Plane of the Ecliptic; the Curve, N *n* the Orbit of the Moon; by the Force whereby the Moon is continually removed out of it, the Way of the Moon is changed, and it goes in the Curve N n, which is more inclined to N n *n* at N than at n; ſo that we muſt conceive the In-
* 4278. clination of the Plane of the Orbit to be twice changed *, whilſt the Moon moves from one Node to the other; therefore this hap-
4295. pens four times *in each Revolution of the Moon, it is twice diminiſhed, and twice again increaſed.*

4296. *Suppoſing the Nodes* N *n*, to be *in the Quadratures*, the Forces
Pl. 127. which *in one Revolution* increaſe *the Inclination* and diminiſh it, are
Fig. 4. equal to one another; for by reaſon of the equal Diſtance of each Node from the Syzygies, the Forces that change the Inclination at N D and *n* E are equal to the Forces in the correſpondent Points
* 4284. in the Arcs D *n* and E N *; by the former the Inclination is in-
† 4293. creaſed, by the latter it is diminiſhed †; the Diminution of the Angle

Angle of Inclination, on account of the firſt, is reſtored by the Action of the ſecond, and here it *is not changed.* In the Motion abovementioned * of the Line of Nodes in reſpect to the Sun, which depends upon the parallel Situation of this Line, the Node N is carried to the Syzygy E. When (for Ex.) the Line of Nodes is come to the Situation M *m*, the Moon in it's Receſs from the Nodes goes through the Quadratures N *n*, in which the Force which changes the Inclination vaniſhes *, and near which, it is the leaſt of all †: But in coming towards the Nodes, the Moon is every where diſtant from the Quadratures, and a greater Force acts upon it *; therefore *conſidering one intire Revolution*, the Increaſe of the Angle of Inclination exceeds the Diminution †; that is, that Angle is increaſed, or, which is the ſame, *the Inclination is diminiſhed*; which obtains every where *in the Motion of the Nodes from the Quadratures to the Syzygies.* * 4291. * 4285. † 4284. * 4284. 4297. † 4293.

When the Nodes are come to the Syzygies, the Inclination of the Plane of the Orbit is the leaſt of all; *for in the Motion of the Nodes from the Syzygies to the Quadratures*, the Plane of the Orbit is continually more and more inclined; for in that Caſe as the Moon goes to the Node, it paſſes through the Quadratures; in it's Receſs from them the Moon is diſtant from the Quadratures, and *in one whole Revolution of the Moon* the Force which increaſes the Inclination * exceeds that which diminiſhes it ‡; therefore *the Inclination is increaſed*; and *it is greateſt of all when the Nodes are in the Quadratures*, where the Diminution of the Angle made by the Plane of the Orbit with the Plane of the Ecliptic is determinated *. 4298. 4299. * 4285. 4293. ‡ 4300. * 4296.

All the Errors in the Moon's Motion, that we have explained, *are ſomething greater in the Conjunction than in the Oppoſition* ‡. 4301. ‡ 4229.

All the diſturbing Forces are determined by diſcovering their Ratio to the Addition of Gravity in the Quadratures *, for which Reaſon they all undergo the ſame Changes as that Addition does; that is, they *are inverſly as the Cube of the Diſtance of the Sun from the Earth* ‡, *which when it remains the ſame, they are as the Diſtance of the Moon from the Earth* *. *Conſidering all the diſturbing Forces together, the Diminution of Gravity prevails* †; which follows immediately from the Progreſs of the Apſides ‡; for it appears from thence, that conſidering ſeveral Revolutions together, the Effect of the Diminution of Gravity exceeds the Effect of the Increaſe of it *. 4302. * 4245. 4247. 4284. ‡ 4222. * 4220. 4303. † 4230. ‡ 3743. 4272. * 630. 631.

4304. Therefore *the Motion of the Moon being conſidered in general, the Gravity of the Moon towards the Earth is diminiſhed, coming near*
* 4303. 4302. *the Sun* *; therefore when it is leſs attracted by the Earth, it recedes more from it than it would recede, if there was no ſuch Di-
4305. minution of Gravity; therefore in that Caſe the Moon's Diſtance
* 582. is increaſed, as alſo *the periodical Time* *; and that Time *is the greateſt, as alſo the Diſtance of the Moon (cæteris paribus) the greateſt,*
‡ 3703. *when the Earth is in the Perihelion* ‡, becauſe then it is leaſt diſtant from the Sun.

CHAP. XVII.

Concerning the Figures of the Planets.

4306. IF we conſider the Figures of the Planets, we ſhall find that they have ſuch Figures which follow from theſe very Laws by which the Syſtem is governed; which is very agreeable to that admirable Order which we obſerve every where, that no Forces
4307. act upon the Planets to deſtroy them; that is, that *the Figure of a Planet, whether it be a primary or a ſecondary Planet, is ſuch as it would acquire, if it wholly conſiſted of fluid Matter*; which agrees with the Phænomena.

4308. Whence it follows, that *all the primary and ſecondary Planets are ſpherical*; for they conſiſt of a Matter whoſe Particles gravitate
* 4047. 4048. towards one another *; from which mutual Attraction a ſpherical Figure is generated in the ſame Manner, as a Drop becomes round
‡ 76. from another ſort of Attraction of the Parts ‡.

4309. *This ſpherical Figure of the Planets is not changed from their Motion round the Sun, or from the Motion of the ſecondary Planets about their primary ones*; becauſe all the Particles are carried by the ſame Motion: But this Figure undergoes ſome Change by the Motion round the Axis, and ſo much the greater as the Motion is ſwifter.

4310. For by the centrifugal Force *Bodies are under the Æquator*; therefore as we demonſtrate in our ſecond Scholium, a *Planet* is every where higher under the Æquator than the Poles;
4311. *and from it's Motion round it's Axis, it acquires the Figure of a Spheroid depreſſed at the Poles*; for the Height is continually diminiſhed as you go towards the Pole; becauſe the centrifugal Force is diminiſhed, by reaſon of the Diſtance from the Axis dimi-
* 607. niſhed *.

If

If what has been demonſtrated be compared with the Phæno- 4312.
mena, it will appear why all the Bodies in our Syſtem are ſpherical *; but that this Figure is not exact, but a little changed by * 3690.
their Motion round their Axis †, though this cannot be obſerved † 4310.
in moſt of them, may be deduced from Obſervations made upon *Jupiter* and the Earth. *Aſtronomers have obſerved, that the Axis of* 4313.
Jupiter is ſhorter than it's æquatorial Diameter; although this Planet be the greateſt of all the Planets, it is moved the ſwifteſt about it's Axis *; and therefore this Difference may be obſerved. * 3731.

The Elevation of the Earth at the Æquator is determined ‡, al- 4314.
though perhaps to the Inhabitants of the other Planets, if there ‡ 4322.
are any, it may not be more ſenſible than the Depreſſion of the Poles of *Mars* to us, which is ſo ſmall that we cannot perceive it.

Let us ſuppoſe the Earth fluid, and it will acquire the abovemen- 4315.
tioned ſphæroidal Figure*; if it conſiſts of heterogeneal Matter, and * 4311.
it's Parts are more denſe, receding from the Center, but equally denſe at the ſame Diſtance from it, there will not be an Æquilibrium, except the Earth be more depreſſed under the Pole, than if it was homogeneous, as we demonſtrate in the 2d Scholium.

Now if we conceive the Parts to cohere towards the Center, the 4316.
Situation of the other Parts cannot be changed by that Means, neither will it be changed, if in ſome Places the Part cohere with one another quite to the Surface, as that really is the Caſe. Therefore the Surface of the Sea has a Figure depreſſed at the Poles.

Since therefore the Shores every where are raiſed but a little above the Surface of the Sea, which contains the Earth, it follows that the Earth is doubtleſs of the ſame Figure as the Sea.

As to what relates to the Figure itſelf, it can be only determined 4317.
from immediate Meaſures and actual Obſervations; as we ſhall ſhew in the Scholia, in which we ſhall demonſtrate what I ſhall now ſay.

Let *e* P E be the half of the Section of the Earth through the 4318.
Meridian; C the Center; P the Pole; E *e* the æquatorial Dia- Tab. 126.
meter. Fig. 9.

This æquatorial Diameter contains 3399474 *Rhynland* Perches. 4319.

The Axis of the Earth = 3380460. 4320.

Therefore the mean Diameter contains 3389940. 4321.

The Æquator is raiſed 9534 *Perches.* 4322.

The Ratio between the Axis and the Diameter is that between 4323.
177,3 and 178,3.

The

4324. The Surface of the Sea muſt be ſo fitted to thoſe, as to be perpen-
* 1413. dicular to the Direction of heavy Bodies *; and the Tangent I F, which agrees with that Surface in the Point I, determines the ho-
† 3909. rizontal Plane †. But it is plain that a Line perpendicular to the
4325. Tangent, which ſhews *the Direction of heavy Bodies*, as I B, *cannot always tend to the Center of the Earth.*

4326. *Yet this Line determines the Height of the Pole*; for that Height
* 3947. is equal to the Angle which I F makes with P C *, or I D, which we ſuppoſe parallel to the Axis, that is perpendicular to *e* E; this Angle is D I F, to which I B D is equal.

4327. If, having drawn *i b* perpendicular to the Surface at *i*, the Angle *i b* D is greater than the Angle I B D one Degree, the Points I and *i* will alſo differ one Degree in Latitude; and the Arc I *i* is of one
4328. *Degree in the Meridian.* If we conceive the whole Arc P I E thus divided into 90 Degrees, theſe *won't be equal to one another*; for every oval Figure is the moſt convex at the Extremities of it's greater Axis, and the leaſt ſo at the Ends of it's leſſer Axis; whence it follows that the Concourſe of the Lines I B, *i b*, that is the Point A, is more removed from the Surface the more I comes towards the Pole; for A is the Center of a Circle, which coincides with the Arc I *i*, and the Radius of the Circle is ſo much the greater, as the Surface is leſs curve; but as I A increaſes, the Arc I *i* does
4329. alſo increaſe. Therefore *the Degrees increaſe as you go towards the Pole, and the Degree at the Pole is the greateſt, and that at the Æquator the leaſt.*

4330. The greateſt Degree contains 29833,4 *Rhynland* Perches; and the leaſt 29334,15.

4331. Therefore the mean Degree is of 29583,77 Perches. This Degree ſcarce differs from that whoſe Latitude in it's middle Point is 45 Degrees.

4332. Between the leaſt and the greateſt Degree, there is a Ratio of 59,75 to 58,75; nearly as 60 to 59.

4333. Gravity alſo differs in different Latitudes, it is the leaſt under
* 4310. the Æquator *, and the greateſt under the Pole, and theſe Gravities are to one another as 201,5 to 202,5.

4334. The Length of a Pendulum which performs it's Vibrations in a Second, was exactly meaſured by the famous Monſ. *Mairan*, who found it to be 440,57 Lines of the Royal *Paris* Foot. The Height of the Pole is 48 Deg. 50′.

4335. The Pendulum being carried to *Lapland*, Obſervations were made there in the Latitude of 66 Deg. 48′, by which it appeared that this Pendulum had performed 86217,5 Vibrations in the ſame Time

Time that at *Paris* it had only performed 86158,4 Vibrations, whence it appeared that the Gravities in thoſe Places were to one another as 729,6 to 728,6 *; how the Gravities of all the Places of the Earth may be compared by this Determination, will be ſeen in the 4th Scholium; and theſe are as the Lengths of Pendulums performing their Vibrations in equal Times *. * 4328. * 431.

The Length of a Pendulum, which performs its Vibration in a Second, is under the Æquator 455,14 Lines of the *Rhynland* Foot, and 456,42 Lines of the ſame Foot at *Paris*; at the Latitude of 86 Deg. 48′ in the Village of *Pello* in *Lapland* 457,08 Lines of the ſame Foot; and at laſt under the Pole 457,40 Lines. 4336.

If Bodies fall freely, we know what Space they go through in 1″ *. And it is in the four Places we have mentioned, if we make uſe of the *Rhynland* Meaſure, of the following Feet, *viz.* 15,597. 15,641; 15,663; 15,674. 4337. * 415. 374.

A Body falling by a mean Gravity, which differs equally from the greateſt and the leaſt, goes through 15,635 Feet, in″. How to determine the mean Gravity, when it is to be compared with that Gravity with which a Body removed beyond the Atmoſphere, comes towards the Earth, has been before ſhewn *. 4338. * 4080.

SCHOLIUM I.

Concerning ſome Properties of the Ellipſe.

LET *e* PE be a Semi-ellipſe; E *e* it's greater Axis: CP it's leſſer Semi-axis; CD any Abſciſs; D I an Ordinate anſwering to it; *e* eE a Semi-circle whoſe Diameter is *e* E. 4339. Plate 172. Fig. 7.

In the Ellipſe we have 4340.

$ED \times De = DK^2$ *, $DI^2 :: CE^2 = Ce^2, CP^2$ †. * 8. 4. 17. El. VI. La Hire, ſect. con. lib. 3. p. 3.

When the Squares are proportional, the Roots alſo are proportional.

Therefore DK, DI :: Ce, CP. † 22. El. 6.

If therefore a Circle be deſcribed, whoſe Diameter is the leſſer Axis of the Ellipſe, and HI be drawn, an ordinate to this Axis, cutting the Circle at *i*, we demonſtrate in the ſame manner this Proportion to be given H *i*, HI :: CF, CE. 4341. 4342. 4343.

The other Things regard the Computations, and muſt be treated algebraically.

We put therefore $z = CE$, the half Axis of the greater Ellipſe. 4344.

$u = CP$, the half Axis of the leaſt. Plate 126. Fig. 9.

$x = CD = HI$, any Abſciſs.

$y = DI$, anſwering to the Ordinate.

Beſides

4345. Beſides let IF be the Tangent of the Ellipſe at I, and IB perpendicular to the Ellipſe, and therefore to the Tangent, in the ſame Point I; the Point of Concourſe of that Perpendicular with the next, which is at an infinitely ſmall Diſtance, that is AI, is the Radius of the Convexity of the
4346. Ellipſe at I, which we call $r = AI$.

4347. The Angle IBD, which this Perpendicular AI makes with the Axis
* 8 El. 6. eE, is equal to the Angle DIF *.

4348. Let s be the Secant of that Angle;
t its Tangent, ſuppoſing the Radius 1.

* 47 El. 1. Therefore $tt + 1 = ss$ *; and $ss - tt$ will be $= 1$.

4350. Let us further put zz, uu :: 1, a;

4351. Therefore $a = \frac{uu}{zz}$.

4352. And az is the Parameter of the greater Axis.

Theſe being thus put, we diſcover the Value of the remaining Lines.

4353. $sy = IF$; becauſe 1, s :: y, IF.

4354. $ty = DF$; becauſe 1, t :: y, DF.

4355. $\frac{sy}{t} = IB$; becauſe t, 1 :: IF (sy), IB.

4356. $\frac{y}{t} = DB$; becauſe t, 1 :: y, DB.

4457.
* 4340. In the Ellipſe it is as we have ſeen before *.

† 4350. $\overline{z-x} \times \overline{z+x} = zz - xx$, yy :: zz, uu :: 1, a †.

4358. We have alſo ∴ CD, CE, CF *; that is,

*La Hire, ſect. con. lib. 3. prop. 8. ∴ x, z, $x + ty$, and $zz = xx + xty$, or $zz - xx = xty$.

And the foregoing Proportion † is chang'd into this,

† 4357. 1 . a :: xty, yy :: xt, y.

4359. Therefore $y = atx$, or $x = \frac{y}{at}$.

4360.
* 4356. And $ax = \frac{y}{t} = DB$ *.

† 4358. If in the Æquation $zz = xx + xty$ †, for y we ſubſtitute atx *, we have

* 4359.
4361. $zz = xx + attxx$; that is, $zz = xx \times \overline{1 + att}$; and $z = x \times \overline{1 + att}^{\frac{1}{2}}$

4362. Whence we deduce $xx = \frac{zz}{1 + att}$; and $x = \frac{z}{\overline{1 + att}^{\frac{1}{2}}}$.

4363.
* 4319. And therefore $y = \frac{atz}{\overline{1 + att}^{\frac{1}{2}}}$ *.

4364. Between the Lines DC, DB, there is a conſtant Ratio of zz to uu,
* 4350. that is, 1, to a *; for they are x and ax †.

* 4344-4360. By Converſion CD, CB :: 1, 1 − a :: Cd, Cb.

4365. Whence it follows Dd = gI, Bb :: 1, 1 − a.

4366. We have alſo GI, gI :: BF, DF, becauſe of the Figures IGig, FBID, which are ſimilar.

Therefore

Therefore joining the Ratios 4367.

GI, Bb : : BF, DF—aDF.

Becauſe of the ſimilar Triangles AGI, ABb, 4368.

GI, Bb : : AI, AB : : BF, DF—aDF *. * 4367.

By converting and inverting, IB, AI : : BD + aDF, BF = BD + DF.

Algebraically $\frac{sy}{t}$ *, r † : : $\frac{y}{t}$ * + aty †, $\frac{y}{t} + ty$. That is, di- * 4355.

viding the Terms of the laſt Ratio by y, and multiplying them by t, † 4346. * 4360.

$\frac{sy}{t}$, r : : $1 + att$, $1 + tt = ss$ ‖. † 4354. ‖ 4349.

Whence $r = \frac{s^3y}{t + at^3} = \frac{s^3ax}{1 + att}$ * $= \frac{s^3a^2}{\overline{1 + att}^{\frac{1}{2}}}$ †. 4369. * 4360. † 4362.

And whence again $z = \frac{r \times \overline{1 + att}^{\frac{1}{2}}}{s^3a}$ and $zz = \frac{rr \times \overline{1 + att^3}}{s^6aa}$. 4370.

Having extracted the Cube Root from each Member of the laſt Æquation, you have 4371.

$$z^{\frac{2}{3}} = \frac{r^{\frac{2}{3}} + r^{\frac{2}{3}}att}{ssa^{\frac{2}{3}}} = \frac{r^{\frac{2}{3}} + r^{\frac{2}{3}}att}{a^{\frac{2}{3}} + a^{\frac{2}{3}}tt} \text{ *.} \qquad \text{* 4349.}$$

Whence is deduced $tt = \frac{r^{\frac{2}{3}} - a^{\frac{2}{3}}z^{\frac{2}{3}}}{a^{\frac{2}{3}}z^{\frac{2}{3}} - ar^{\frac{2}{3}}}$.

By the Help of the Æquations, which we have hitherto drawn from the Nature of the Ellipſe, we may diſcover ſeveral Lines in a given Ellipſe: but in all of them we ſuppoſe the Form of the Ellipſe, or the Ratio between the Axes to be known; but if a be ſought, and the Convexity of the Figure be given in two Points, for which alſo is given the Inclination of the Tangent to the Axis, by the following Method we ſhall inveſtigate an Æquation, which ſhews the Value of a. 4372.

r, s, and t are given; we ſuppoſe r, s, and t to ſignify the ſame Quantities given for another Point. Then we have 4373.

$$zz = \frac{rr \times \overline{1 + att^3}}{s^6aa} = \frac{\mathrm{rr} \times \overline{1 + \mathrm{att}^3}}{\mathrm{S}^6aa} \text{ *.} \qquad \text{* 4370.}$$

Whence multiplying the Æquation by $s^6\,\mathrm{S}^6\,aa$, and extracting the Cube Root from each Member, we deduce the Æquation. 4374.

$$r^{\frac{2}{3}}\mathrm{SS} + r^{\frac{2}{3}}att\mathrm{SS} = \mathrm{r}^{\frac{2}{3}}ss + \mathrm{r}^{\frac{2}{3}}\mathrm{tt}ss.$$

Which gives $a = \frac{\mathrm{r}^{\frac{2}{3}}ss - r^{\frac{2}{3}}\mathrm{SS}}{r^{\frac{2}{3}}tt\mathrm{SS} - \mathrm{r}^{\frac{2}{3}}\mathrm{tt}ss}$.

Each of the Æquations expreſs the Theorem, which is made uſe of in the Computations concerning the Figure and Magnitude of the Earth, and

does immediately ſhew what Operations are to be gone through for the Solutions of particular Queſtions.

SCHOLIUM II.

Concerning the Figures of the Planets in general.

4375. * 4311. WE have ſaid, that ſpherical Planets made of fluid Matter, change their Figure, by their Revolution about their Axis *; we ſhall now conſider this Change, and immediately apply our Reaſonings to the Earth.

Pl. 126. F. 8. Let P be the Pole; C the Center; E*e* the Diameter of the Æquator; we conceive the Earth fluid and homogeneous, and that it turns about it's Axis. We ſuppoſe that it has acquired the Figure *e* P I E, into

4376. whoſe Nature we are firſt of all to inquire. If ſome of the Parts cohere, the Fluid will preſs them in the ſame manner as before the Coheſion, and the Figure will not be changed; neither can it be changed, although in ſome Places the Parts cohere from the Center quite to the Surface; therefore the Surface of the Sea would acquire the ſame Figure then, that it

* 3315. would do if the Earth was wholly fluid, as we have already taught *.

4377. Now let us ſuppoſe Tubes to be placed as P C, H I, C E, which communicate; the Fluid will diſpoſe itſelf in them, at thoſe Heights in P,

* 4376. I, E, at which it was before *; therefore the right Columns C P, C E, will be in Æquilibrio; as alſo the right Column H P, with the oblique one H I.

4378. The Earth being at reſt, the Columns C P, C E are equal, as alſo C P,

Pl. 126. Fig. 7. C F, then the third H I, which is in the ſame Caſe as H*i*, is equal to the Co-ſine of the Altitude of the Pole.

4379. Let us ſuppoſe Gravity on the Surface of the Earth to be repreſented by the Radius P C or *i* C, or F C; then the Gravity in every Point will

* 4089. be repreſented by the Diſtance of thoſe Points from the Center *; ſo Gravity at L is as L C, and at *l* as *l* C.

4380. If we reſolve the Gravity acting in the Direction *i* C, into two Preſ-

* 319. ſures along *i d* and *i* H, they will be proportionable to thoſe Lines *. In the ſame manner if the Gravity L C of the Point L be reſolved into two Preſſions along L*l*, and L H, they will alſo be proportionable to thoſe Lines.

Whence it follows, becauſe *i* H and *d* C are equal, as alſo L H and *l* C, if we reaſon in the ſame manner concerning all the Points of the Line *i* H, that the whole Preſſion of the Column *i* H, againſt the Point H, is equal to the Weight of the Column *d* C.

4381. Now if we ſuppoſe the Earth to turn about it's Axis, the Fluid will become lighter in the Tube C E, and Gravity will be diminiſhed along the whole Length of the Tube according to the ſame Ratio; for that, and the

* 4089. 607. centrifugal Force are every where as the Diſtance from the Center *; therefore

therefore in Proportion of that Diminution of Gravity the Column C E is extended, for it will not be in Æquilibrio with the Fluid in the Tube P C, unleſs the Height of that, be to the Height of this; as the Gravity in any Point of this, to the Gravity in a correſpondent Point of that. For then the Column EC preſſes, as much as this preſſed before when it had the Height C F; and becauſe Gravity is always unchanged in it's Ratio of the Diſtance from the Center, the Part C D, which preſſes, as much as C *d* preſſed, is had by this Proportion:

C *d*, C D : : C F, C E.

4382.

The Earth being at reſt, the ſingle Points of that Part C *d* of the Column C E, preſs as much, as, in that Caſe, the correſpondent Points of the Column *i* H, do; but if the Earth turns about it's Axis, the Column *i* H is moved in the ſame manner as C *d*; and the Preſſure of this in each Point is changed in the ſame manner as the Preſſure of the other; therefore, that after the Preſſure has been diminiſhed by the centrifugal Force; this may become equal to the Preſſure that it had before, it muſt extend itſelf to I, ſo that H I may become equal to C D; and the like Demonſtration may be applied to all the Lines as H I. 4383.

When the Figure of the Earth is changed by its turning about it's Axis, the Diſtance C P is diminiſhed, but the Demonſtration is not changed; for C P remaining the ſame, we may ſuppoſe Matter to be added outwardly, as much as is wanting to reſtore the Æquilibrium. 4384.

We have therefore this Property of the acquired Figure, H *i* = C *d* is to H I = C D, as C F is to C E *; which is the Property of the Ellipſe †. 4385.

* 4382.

† 4342.

We muſt obſerve beſides, that the Figure muſt neceſſarily be ſo changed, that the Direction of Gravity may be perpendicular to the Surface, otherwiſe, in reſpect of fluid Subſtances, the Figure would again be changed by their flowing; therefore the Earth can only acquire an elliptic Figure in thoſe Caſes, in which, ſuppoſing it to be ſuch, the Direction of Gravity is perpendicular to the Surface, which only obtains, when the Circle differs but little from an Ellipſe, which happens in the Earth. 4386.

We have ſuppoſed Gravity at *i* to be repreſented by *i* C *, whence we have deduced the Preſſure along *i* H, to be expreſſed by that Line itſelf; and therefore that *i* I repreſented the Diminution of Preſſure from the Revolution; for the intire Preſſure muſt be increaſed by that Quantity, that the Æquilibrium may be reſtored, when it is diminiſhed by the Revolution about the Axis. 4387.

The Particle at *i* is then drawn along *i* C, and *i* I, by Forces proportionable to thoſe Lines, and drawing I *c*, parallel to *i* C, the Particle is driven along *i c*, by an Action proportional to that Line *. 4388.

* 318.

By theſe Actions, the Particles are preſſed every where between *i* and I, and the Direction of Gravity in I is parallel to *i c*, and alſo proportional to that Line, as long as *i* I is ſmall; if the Earth remaining ſpherical, there ſhould be given a Particle at I ſeparated from the Earth, the Change of the Direction of Gravity on account of the centrifugal Force 4389.

would be ſomething leſs, becauſe the Direction of Gravity itſelf would not be iC or Ic, but IC; now Matter added increaſes the Deflection, and the Direction of Gravity IG, as to Senſe is parallel to ic; and therefore as to Senſe it is alſo perpendicular to the Curve at I, as I ſhall deduce from what has been before demonſtrated.

4390. We conſider the Figure differing but little from a Circle, therefore Cc and tG muſt be ſmall, in reſpect of DC; Cc and cG are alſo equal as to Senſe, this laſt ſcarce wanting any thing of Ii; therefore DC, Dc, DG are in continued Proportion; at leaſt they may be looked upon as ſuch without any ſenſible Error

4391. Since the following are equal IH, DC, as alſo Ii, Cc; iH will alſo be equal to Dc;

* 4343. But $CE, CF = CP :: IH, iH$*.

Therefore $CE, CP :: DC, Dc$.

† 4390. And $CE^2, CP^2 :: DC^2, Dc^2 :: DC, DG$†.

* 4364. Whence it follows that IG is perpendicular to the Ellipſe*, which was to be demonſtrated.

4392. From what has been demonſtrated in N° 4388. it follows that Gravity is the greateſt of all under the Pole, and that it is continually diminiſhed receding from the Pole, and the leaſt of all under the Æquator, as

* 4333. we have taught*.

4393. Now to determine the Law of this Diminution, let us conceive the Arc cn to be deſcribed with the Center i, through the Point c; Cn expreſſes the Diminution in Queſtion; for Ci, equal to CP, ſhews the Gravity under the Pole, and ic the changed Gravity, which we want.

4394. The Diminution of Gravity under the Æquator is as FE, when the

* 4381. Gravity under the Pole is expreſſed by CP, as we have ſeen*; therefore the Diminution under the Æquator is to the Diminution at I, as FE to Cn; that is in the Ratio compounded of FE to Ii, and of that to Cn.

The firſt of theſe Ratios, namely that of FE to Ii, is that which is

* 4385. given between CF, or Ci, and iH*. The ſecond which is given between Ii and Cn, is the ſame with the firſt; for Ii is equal to Cc, and Cc is to Cn, as Ci to iH, by reaſon of the ſimilar Triangles CiH and Ccn; becauſe the little Arc cn may be conſidered as a right Line perpendicular to Ci. Therefore the Ratio between FE and Cn is the duplicate Ratio of that which is given between Ci and iH; and therefore

4395. *the Diminution of Gravity is* every where as the Square of the Line iH, that is, *as the Square of the Co-ſine of the Latitude of the Place.*

4396. Gravity is increaſed receding from the Æquator, till it is the greateſt of all under the Pole; and the Augmentation every where, is the Difference between the greateſt Diminution, namely that which has place under the Æquator, and that which obtains in the Place in Queſtion: therefore in I that Augmentation is, as the Difference of the Squares Ci

* 41. El. 1. and Hi, which is equal to the Square of HC*, or id; that is, the *In-*

4397. *creaſe of Gravity*, in any Place, *is as the Square of the Sine of the Latitude of the Place.*

I have

I have conſidered no other Change of Figure but that ariſing from the centrifugal Force, but there is another Change of Figure joined with it; for ſince Gravity tends to every Particle of Matter, the reſpective Situation of thoſe Particles being changed, the Gravity of the Particles compounding the Planet is ſo changed, that even ſetting aſide the centrifugal Force, Bodies are lighter under the Æquator than at the Poles*. Whence it follows, that a Planet is more depreſſed at the Poles, when it revolves about it's Axis, than what follows from the centrifugal Force alone. 4398. * 4389.

In all theſe Caſes we have ſuppoſed the Planet homogeneous, and inveſtigating the Thing farther, what would be the Figure of it, that is, what would be the Ratio between the Axis and the æquatorial Diameter, in ſuch an Hypotheſis; but the Meaſures taken in ſeveral Places of the Earth do not agree with ſuch a Figure. 4399.

Therefore we will examine how the Figure of a Planet may be differently varied by it's Motion round it's Axis, according to it's different Conſtitution, though, ſetting aſide the ſaid Motion, we conceive it to be fluid and ſpherical, but of different Denſity, at different Diſtances from the Center; but we muſt return to the Caſe which we have examined. 4400.

We conceive a Planet ſpherical, at reſt, of homogeneous and fluid Matter. A Column as CE, is drawn towards the Center by Gravity; if the Planet turns about it's Axis, that Gravity is diminiſhed by the centrifugal Force; the Figure of the Planet is then changed, and depreſſed at the Poles as we have ſhewn *. But it appears clearly that this Change of Figure depends upon the Ratio which is between the centrifugal Force and Gravity; which we alſo refer to the ſecond Cauſe of Change, which follows from this firſt †. 4401. * 4381. * 4398.

The Figure of a Planet is more changed, and more raiſed under the Æquator, and therefore depreſſed under the Poles, *if other things remaining as they are, the centrifugal Force be increaſed*; for this Force diminiſhes the Gravity, and is the Cauſe of extending the Column CE. 4402.

Neither is it leſs evident, that *the* ſpherical *Figure is* alſo the *more changed, if the centrifugal Force remaining, the Gravities* of the Columns CP, CE *are leſſened*; if for Ex. the Gravity of the Column CE be diminiſh'd one hundredth Part of the centrifugal Force, the Height CE will exceed CP by ſuch a Part; and by reducing the Gravity of the Columns to half, the centrifugal Force, which we ſuppoſe to remain the ſame, which was the hundredth Part of the former Gravity, is now equal to two hundredth Parts of the laſt Gravity, and the Height CE will exceed the Height CP one 50th Part, and therefore will more change the Figure. 4403.

Let us again conceive the Planet ſpherical, made of fluid Matter, or at leaſt ſoft enough, of the ſame Denſity at equal Diſtances from the Center, but which grows continually denſer receding from it. If ſuch a Planet revolves round it's Axis, the Figure will be changed, and what we have demonſtrated of the Æquilibrium of the Columns PC, CE, will alſo have Place here. 4404.

4405. If we compare ſuch a Planet with an homogenous one of the ſame Bigneſs, and which contains an equal Quantity with the heterogeneous one propoſed, all the ſingle Columns which tend from the Surface to the Center, will have leſs Gravity in the heterogeneous than in the homogeneous Planet.

4406. For *if, the homogeneous Planet being given, the Matter be every where removed towards the Surface, and* ſo *the Denſity be increaſed in receding from the Center*, and the Point H be taken at Pleaſure, which we ſuppoſe to be transferred to *h*, then the Matter, which was contained in the Globe whoſe Semi-diameter was C H, will now fill a greater Globe, whoſe Semi-diameter is C*h*, and in that laſt Caſe the Quantity of Matter is the ſame,
* 4117. which draws that Particle towards the Center * ; wherefore the Gravities
4118. of this Particle in theſe different Circumſtances, are in a duplicate inverſe
* 4117. Ratio of the Diſtances C H, C*h* *, and the Gravity is leſs in the heterogeneous Globe.

4049. But this Demonſtration may be referred to every one of the Parts of the whole Globe, according to whatever Law the Denſity increaſes receding from the Center, becauſe all the Particles are removed from the Center, when *none but the Particles in the Surface* remain, and *keep their Gravity*; *and* therefore *every one of the Columns extended from the Surface to the Center*, whoſe Gravity is made up of the joint Gravities of the Particles, *become lighter*.

4407. *In ſuch a changed Planet* alſo, *the centrifugal Force of every one of the*
* 607. *Particles, except thoſe that are in the Surface, is increaſed* * ; for each of them deſcribe bigger Circles than in the homogeneous Planet.

4408. *Therefore heterogeneous Planets, ſuch as we have above deſcribed* †, *while*
† 4404. *they revolve about their Axis, do*, upon a double Account, *change their*
* 4402.4403. *Figure more than homogeneous ones* *.

4409. We prove by a like Demonſtration, that *Planets do leſs change their Figure*, that is, are leſs depreſſed at the Poles, *if the Denſity be increaſed in going towards the Center*.

4410. Hitherto we have conſidered a ſpherical Planet when it is at reſt; it may alſo have another Figure, if we ſuppoſe a Kernel or Nucleus of ſolid Matter in the Middle: for if in ſuch a Caſe it has the Figure of a Spheroid, and be encompaſſed round with fluid Matter, the Figure of the Planet will be different, according to the different Figure of the Nucleus, and it's Denſity.

4411. But whatever Figure a Planet has, it is depreſſed towards the Pole by it's Motion about it's Axis, and the æquatorial Diameter is increaſed;
4412. but it does not neceſſarily follow from thence that that Diameter, however increaſed, exceeds the diminiſhed Axis; ſo that *nothing, except from immediate Obſervations, can be determined concerning the Figure of a Planet*; which Method we ſhall follow in the next Scholium for determining the Figure of the Earth.

SHO-

SCHOLIUM III.

How to determine the Figure of the Earth.

WE have ſaid that the Earth was not ſpherical, but that the æquatorial Diameter was longer than the Axis *, and therefore that it had ſuch a Figure as it might have acquired by a Motion about it's Axis, if it had been ſpherical †; and as this Figure differs but very little from a Circle, we ſuppoſe the Section through the Axis, that is the Plane of a Meridian to make an Ellipſe, one of whoſe Axes is the Diameter of the Æquator *. 4413. * 4311. † 4008. * 4385.

We alſo ſuppoſe that the Decrements of Gravity, receding from the Pole, follow the duplicate Ratio of the Co-ſines of the Latitudes of Places *; that is that the Increaſes of Gravity, receding from the Æquator, follow the duplicate Ratio of the Sines of the ſame Latitudes of Places †. 4414. * 4395. † 4397.

We have ſhewn that the Figure muſt be determined from Obſervations *; for that Reaſon therefore we have choſen two Meaſures taken in different Places, that is in *Lapland* and in *France*, and deſcribed in two ſmall Treatiſes by the famous Monſ. *de Maupertuis*, to whom they are principally owing. We prefer theſe to others taken in various other Countries; becauſe it is plain from the Deſcription of the Inſtruments, and the Cautions which the Obſervers affirm that they took, they could fall into but very ſmall, and ſcarce ſenſible, Errors. 4115. * 4412.

What relates to Gravity, we deduce from the Length of a Pendulum vibrating Seconds, meaſured in *France* with the utmoſt Care by that famous Philoſopher Monſ. *de Mairan*, and from the Obſervations made by the ſame *French* Mathematicians who took Pains about meaſuring the Figure of the Earth in *Lapland*, with the ſame Pendulum in both Countries, *viz.* *France* and *Lapland*. 4416.

Now let C P be the Semi-axis of the Earth; E *e* the Diameter of the Æquator; and P I E an Arc of the Meridian. A ſmall Part of that Meridian *i* I is meaſured by ſurveying on the Surface of the Earth itſelf. Now if we conceive the Lines *h i*, B B, which we ſuppoſe vertical, and therefore perpendicular to the Surface of the Earth, to be continued to the fixed Stars, an Arc in the Heavens intercepted between thoſe Lines is meaſured by Aſtronomical Obſervations; that is, an Arc which meaſures the Angle I A *i*, and determines the Arc I *i*, in the Meridian. 4417.

By ſuch Operations it has been diſcovered, that the Arc I *i*, where the Angle I A *i* is of 0. Deg. 57′.28″,67, contains 55023,47 *French Toiſes* (or Fathom) when the Latitude of the middle Point of the meaſured Arc was of 66 Deg. 20′. From which it follows that a Degree of the Meridian between the Points of Latitude of 65 Deg. 50′. and 66 Deg. 50′ contain 57437,9 *French Toiſes*; that is 29752 *Rhynland* Perches. 4418.

It

4419. It has alſo appeared from ſuch kind of Obſervations, that a Degree of the Meridian between the Latitudes of 48 Deg. 52′, and 49 Deg. 52′ contains 57183 *French Toiſes*, or 29620 *Rhynland* Perches.

4420. The Bigneſs of one Degree being given, one may eaſily find the Radius of the Circle; for the Radius is to one Degree, as 180 × 113 to 355, that is as 4068 to 71; therefore we eaſily determine the Radii of the Convexity in the middle Points of the mentioned Degrees, that is, we have *r* for two Places; in which the Angles as I B E, which the Perpendiculars to the Surface make with the Plane of the Æquator, are of 66 Deg. 20′, and 49 Deg. 22′.

4421. Let us therefore ſuppoſe *r*, *s* and *t* to ſtand for thoſe Things, which above were expreſſed by the ſame Letters, but that they belong to the firſt Angle; that is, *r* is the Radius of Convexity, ſuppoſing the Lati-
* 4345. 4346. tude of 66 Deg. 20′ *; *t* is the Tangent, and *s* the Secant of the ſame
† 4348. Angle †; in the ſame manner we ſuppoſe r, t, s, to expreſs the ſame Quantities for the Latitude of 49 Deg. 22′; in all which we ſuppoſe the Radius of the Circle, when *t*, *s*, t s, expreſs the ſaid Quantities, to be
* 4348. equal to Unity, as above *.

4422. All that we have explained concerning the Computation of the Lines in an Ellipſe in the 1ſt Scholium, may be referred to the Earth, whoſe Section through the Meridian, we ſuppoſe to be repreſented by the ninth Figure itſelf.

But before all things we muſt determine the Proportion between the
* 4344. Axes of the Ellipſe, that is, between C P and C E, or *u* and *z* *.

4423. We therefore ſeek *a* †; becauſe 1, *a* : : *zz*, *uu* *. The Computa-
† 4374. tion is eaſy by Logarithms; and we find $r^{\frac{2}{3}}\, ss = 136900{,}7$; $r^{\frac{2}{3}}\, ss =$
* 4350. $52171{,}2$; $r^{\frac{2}{3}}\, tt\, ss = 271604$; $r^{\frac{2}{3}}\, tt\, ss = 185916{,}9$; whence we de-
* 4374. duce $a = \frac{84720{,}5}{85688{,}1}$ *.

4424. That is, *z*, *u*, : : 178,3. 177,3. nearly.

4425. We have now two Ways to diſcover z (CE) † whether we make uſe
† 4344. of *r*, *s*, *t*, or r, s, t, *; and E*e* the Diameter of the Æquator is of
* 4370. 3399474 *Rhynland* Perches; whence we deduce, that the Axis contains
* 4424. 3380406 Perches †. And the mean Diameter is of 3389940 Perches.

4426. We find the Radius of Convexity in any Point, when it's Latitude is
* 4369. given by this Æquation, $r = \frac{as^3 z}{\sqrt{(1 + att)^3}}$ *.

4427. Under the Pole the Angle I B E is a right one; therefore *s* and *t* are equal and infinite; therefore $r = \frac{z}{\sqrt{a}}$. Then the Radius of Convexity is the greateſt of all.

4428. But the Convexity is the greateſt, and the Radius of Convexity the leaſt, under the Æquator. Then $s = 1$, and $t = 0$; whence $r = az$.

We

We may diſcover the Magnitude of a Degree of Latitude from the Radius of Convexity; for 4068,71 : : r, to the required Degree *: and thus we have determined the greateſt and the leaſt Degree †. If the Magnitude of any Degree of Latitude whatever be given, the Radius of Convexity is determined *; and the Latitude to which this anſwers, may be diſcovered by the following Æquation, $tt = \frac{r^{\frac{2}{3}} - a^{\frac{2}{3}} z^{\frac{2}{3}}}{a^{\frac{2}{3}} z^{\frac{2}{3}} - a r^{\frac{2}{3}}}$ †; for the Tangent being given, the Angle is given. What has been ſaid of the Place of the mean Degree is built upon this Computation. 4429. * 4420. † 4330. 4430. * 4420. † 4371.4331. 4431.

We alſo now eaſily find the Radius of any Circle of Latitude, namely HI = CD = x; for $x = \frac{z}{\overline{1 + att}^{\frac{1}{2}}}$ *; and 4068,71 : : x, to the Degree of Longitude in that Latitude †. * 4362. † 4420.

SCHOLIUM IV.

The Determination of Gravity in different Places.

WE have ſeen before from Obſervations made with a Pendulum carried from one Place to another, that it is evident, that Gravity at the Altitude of the Pole of 48 Deg. 50′. is to the Gravity under the Altitude of the Pole of 66 Deg. 48′, as 728,6 to 729,6 *; which being given, the Gravities in all Places of the Earth are compared together, by calling to our Aſſiſtance, what we have demonſtrated above †, and this is the Rule. 4432. * 4335. † 4414.4397.

As the Difference of the Squares of the Sines of the ſaid Angles of 66°. 48′; and 48°. *to the Difference of the Square of the Sines of one of theſe Angles, and of any Angle given; ſo is the Difference of the Gravities in the firſt of theſe Places, to the Difference of the Gravities in the laſt.* 4433.

But all the Computations become more ſimple if firſt we diſcover the Gravity under the Æquator, becauſe the Sine of Latitude and therefore it's Square = 0. 4434.

The Lengths of Pendulums which perform their Vibrations in equal Times, are to one another as the Gravities *, and are compared together in the ſame manner as them. 4435. * 431.

We have ſeen that the Length of a Pendulum, which vibrates Seconds at *Paris*, is 440,57 Lines of the *Paris* Foot, and therefore 456,42 Lines of the *Rhynland* Foot, whence we reaſon thus; 4436.

728,6; 729,6 : : 456,42; 457,08 *. * 4335. 431.

And we have the Length of a Pendulum for an Height of the Pole of 66°. 48′.

As the Difference of the Squares of the Sines of the Latitudes 66°. 48′. and 48°. 50′. to the laſt Square, ſo the Difference of the Lengths found, 4437.

found, 0,66 to the Difference of the *Paris* Pendulum from the Pendu-
* 4433.4434. lum under the Æquator *, which is diſcovered to be 1,28; and the Length of that Pendulum is 455,14.

4438. As the Square of the Sine 48°. 50′. to the Square of the Radius, ſo is 1,28 to 2,26 the Difference of the Length under the Æquator and the Pole, in which Place therefore the Length of a Pendulum is 557,40.

4439. For any other Latitude whatever we work thus: As the Square of the Radius, namely of the Sine of the Latitude of the Pole itſelf, is to the Square of the Sine of the given Latitude, ſo is 2,26, the Length to be added to a Pendulum under the Æquator to have the Pendulum under the Pole, to the Length to be added to that ſame Pendulum under the Æquator, to have a Pendulum that will vibrate Seconds in a Place pro-
* 4433. poſed *.

CHAP. XVIII.

The phyſical Explanation of the Motion of the Earth's Axis.

4440. THAT the Nodes of the Moon go back, that is, are moved
* 4289. in *Antecedentia* *, and that the Inclination of it's Orbit is
† 4295. liable to Change †, we have already demonſtrated; let us conceive ſeveral Moons to be at the ſame Diſtance, revolving in equal Times about the Earth, in a Plane inclined to the Plane of the Ecliptic; it is evident they will all be agitated by the ſame Motions: Let us conceive the Number of the Moons to be increaſed, ſo as to touch one another, and form a Ring, whoſe Parts cohere; whilſt one Part of the Ring is attracted, to increaſe the Inclination, the other Part is agitated by a contrary Motion, to diminiſh it's In-
* 4293. clination *; the greater Force in this Caſe prevails, that is, *in the*
4441. *Motion of the Line of the Nodes, from the Quadratures towards the Syzygies, the Inclination of the Ring is diminiſhed in each of it's Re-*
* 4297. *volutions* *; *and it is the leaſt of all when the Line of Nodes is in the*
† 4298. *Syzygies* †. On the contrary *it's Inclination is increaſed, when the*
4442. *Line of Nodes is carried from the Syzygies towards the Quadratures* *;
* 4299. *and it is the greateſt of all, when the Line of the Nodes is in theſe*
† 4300. *laſt* †. *The Line of the Nodes is continually carried in* Antecedentia, *unleſs when it is at reſt in the Syzygies* *.
4443.
* 4289.4292. *If the Quantity of Matter in the Ring be diminiſhed it's Motions*
4444. *will not be changed*; becauſe they depend upon Gravity, which acts
* 4048. equally upon every Particle of Matter *.

If

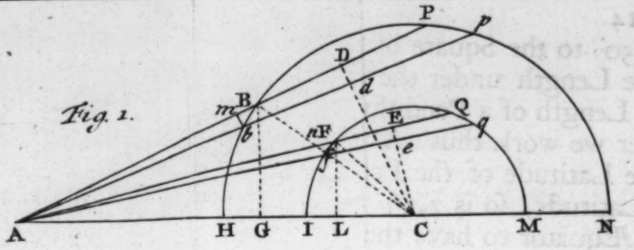


Fig. 1.

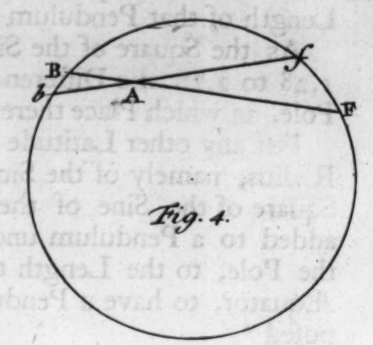


Fig. 4.

Fig. 2.

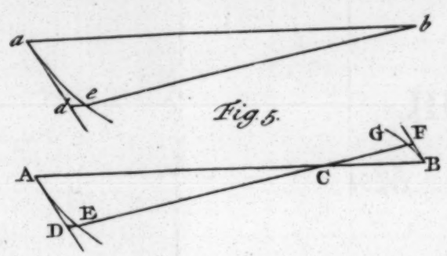
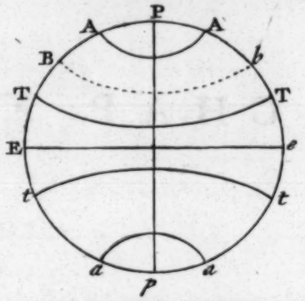


Fig. 5.



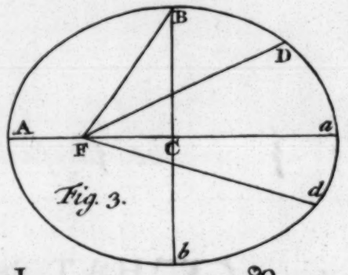


Fig. 3.

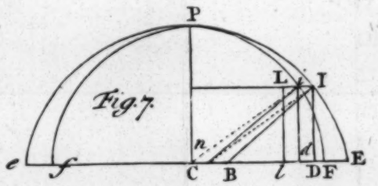


Fig. 7.

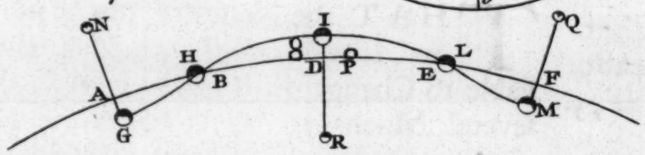


Fig. 6.

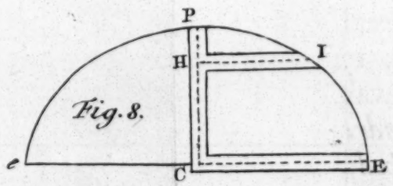


Fig. 8.

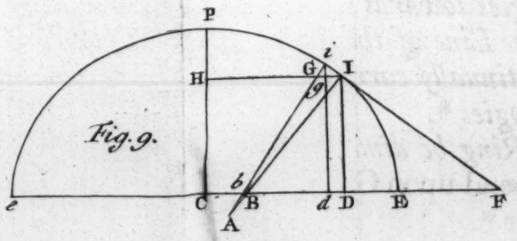
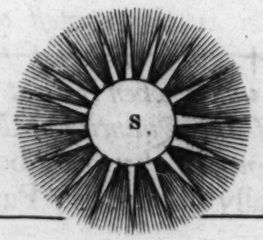


Fig. 9.



If the Diameter of the Ring be diminiſhed, theſe Motions are diminiſhed in a Ratio of this Diminution *, but none of them wholly vaniſh; and *it is agitated by the ſame Motions though leſs.* 4445. * 4302.

Let us conceive the Earth to be ſpherical; and in the Plane of the Æquator, which makes an Angle of 23 Deg. 29 Min. with the Plane of the Ecliptic, let there be a Ring, revolving in the ſame Time as the Earth; let it be diminiſhed ſo as to touch the Earth and cohere with it; by this the aforeſaid Motion of the Ring will not be deſtroyed; for ſince the Earth is kept in a determinate Situation by no Force, it yields to the Impreſſions of the Ring, whoſe Agitations are yet diminiſhed, the Matter to be moved being increaſed, and the moving Force remaining the ſame. 4446.

And this is truly the Caſe; for the Figure of the Earth is ſpherical, encompaſſed with the Ring at the Æquator, whereby the Earth is more elevated towards the Æquator *, the Line of Nodes of which Ring is the Section of the Planes of the Æquator and Ecliptic. Whence we deduce the following Concluſions. 4447. * 4311.

In the Æquinoxes, the Inclination of the Æquator is leaſt of all *; and therefore *the Inclination of the Axis is the greateſt*; for it makes a right Angle with the Plane of the Æquator †. Afterwards, the Inclination of the Æquator is increaſed, that is, *the Inclination of the Axis is diminiſhed, till the Sun comes to the Solſtices, where this Inclination of the Axis is the leaſt of all*, and that of the Æquator is the greateſt *. 4448. * 4441. † 3879. 4449. * 4442.

Therefore *twice in a Year the Inclination of the Axis of the Earth is diminiſhed and twice increaſed.* And *the Section of the Plane of the Æquator with the Plane of the Ecliptic*, which *is at reſt in the Æquinoxes, the reſt of the Time is moved in* Antecedentia *. 4450. 4451. * 4443.

The Plane of the Æquator is alſo inclined to the Plane of the Moon's Orbit; for it makes a ſmall Angle with the Plane of the Ecliptic ‡; and therefore the Moon acts in the ſame manner upon the Ring as the Sun; and although the Moon be leſs, yet, becauſe it is much leſs diſtant than the Sun, it exerts a greater Action upon the Ring. Wherefore alſo *the Inclination of the Axis of the Earth to the Plane* of the Moon's Orbit * (and conſequently to the Plane *of the Ecliptic) is twice changed in every Revolution, and twice reſtored by the Action of the Moon: and the Section of the Plane of the Æquator*, with the Plane of the Moon's Orbit *, is carried in *Antecedentia:* From which Motion it neceſſarily follows, that the Section of the Plane of the Æquator, *with the Plane of the Ecliptic, changes it's Place.* 4452. ‡ 3742. 4453. * 4450. * 4451.

4454. *The Changes of the Inclination of the Axis are too ſmall to be ob-*
4455. *ſerved; but the Change of Place of the Line of the Æquinoxes, and the Motion of the Axis* which follows from it, being always carried the ſame Way, *at laſt becomes ſenſible*; and from theſe follow the Phæ-
* 4017. 4018. nomena before explained *.

CHAP. XIX.

Concerning the Tides.

4456. SINCE the Tides depend upon the abovementioned Actions of the Sun and Moon, they muſt not be neglected here.

That we may explain them from the Principles already laid down, we muſt conſider that the Earth, as alſo all Bodies near it,
* 4047. gravitate towards the Moon *; therefore the Particles of Water in the Earth's Surface, which tend towards the Earth's Surface, which tend towards the Center of the Earth, or near it, are carried with
‡ 4325. it towards the Moon ‡. Since alſo the ſolid Maſs of the Earth is carried towards the Moon, according to the Laws which would obtain, if all the Matter of which it conſiſts was collected in it's Cen-
* 4082. ter *; *what has been demonſtrated in* Chap. xvi. *of the Action of the*
4457. *Sun upon the Moon*, falling towards the Earth, whilſt with the Earth it goes towards the Sun, *may be applied to the Action of the Moon upon the Particles of Water in the Earth's Surface*, which don't cohere with the Maſs of the Earth, but tend towards it's Center, and continually with it's Maſs fall towards the Moon; by which
* 4210. Force, as we have ſhewn *, the Earth is kept in it's Orbit, about the common Center of Gravity of the Earth and Moon.

4458. Let S be the Moon; A L B *l* the Surface of the Earth, whoſe
Plate 127. Maſs tends towards the Moon, as if it was all collected at T; by
Fig. 1. the Action of the Moon, the Particles of Water, A and B, acquire
* 4219. a greater Gravity towards T *; on the contrary, the Particles at L *l*,
† 4225. 4228. loſe of their Gravity †; whence we deduce, that if the whole Earth was covered with Water, there would not be an Æquilibrum unleſs this Water was more elevated in the Points L and *l*, than in a whole Circle 90 Deg. diſtant from theſe Points; and therefore paſ-
4459. ſing through the Points A and B; and therefore *by the Action of the Moon the Water acquires a ſpheroidical Figure, formed by the Revolution of an Oval about it's greater Axis, which, being continued, goes through the Moon.*

Let

Let us ſuppoſe the Moon in the Æquator; all the Sections of the Earth which are parallel to the Æquator, as they are alſo parallel to the Axis of the Spheroid *, are oval, whoſe greater Axes paſs through the Meridian of the Moon; whence it follows, that *the Earth being at reſt, in any Circle of Latitude, the Water is more elevated in the Meridian in which the Moon is, and in the oppoſite Meridian, than in the intermediate Places.* 4460. * 4459. 4461.

Definition.

The lunar Day *is the Time ſpent between the Moon's going from the Meridian and coming to it again.* This Day is divided into 24 lunar Hours: It is 50 Minutes longer than the natural Day. 4462.

From the Motion of the Earth round it's Axis, every lunar Day, every Place paſſes through the Meridian of the Moon; and the oppoſite Meridian, that is, twice paſſes through that Place, where the Water is raiſed *by the Action of the Moon*, and twice through that Place, where the Water is depreſſed by the ſame Action *; and ſo *in a lunar Day the Sea is twice elevated, and twice depreſſed, in any aſſigned Place.* 4463. 4464. * 4461.

By the Motion of the Earth round it's Axis, the elevated Water continually recedes from the Meridian of the Moon; yet by the Action of the Moon *, the Axis of the Spheroid paſſes through the Moon; therefore the Water is continually agitated, that the Elevation, which on account of the Motion of the Earth is removed, may be brought under the Moon. Therefore the Water continually flows from A and B towards L and *l*, whilſt by the Motion of the Earth, the Elevation is carried from L towards B, and from *l* towards A; that is between L and B, as alſo between *l* and A, there are two contrary Motions, by which the Water is accumulated more; ſo that the greateſt Elevations are between theſe Points (viz.) not directly under the Moon, but on one Side of that Point, and likewiſe aſide of the oppoſite Point, that is in any Place, *the Water is moſt elevated, two or three Hours after the Moon has paſſed the Meridian of the Place, or the oppoſite Meridian.* 4465. * 4459. 4466.

*The Elevation of the Waters towards the Moon a little exceeds the oppoſite one **, *the Aſcent of the Water is diminiſhed as you go towards the Poles, becauſe there is no Agitation of Water there.* 4467. 4468. * 4457. 4229.

What has been demonſtrated, in relation to the Moon, may be applied to the Sun; therefore *from the Action of the Sun, every natural Day the Sea is twice elevated, and twice depreſſed **. *This* 4469. * 4464.

Agitation

4470. *Agitation is much leſs*, on account of the immenſe Diſtance of the
4471. Sun *than that which depends upon the Moon*; yet *it is ſubject to the ſame Laws.*

4472. The Motions, which depend upon the Actions of the Moon and
4473. Sun, are not diſtinguiſhed but confounded, and *from the Actions of the Sun, the lunar Tide is only changed, which Change varies every Day*, by reaſon of the Inequality between the natural and lunar
* 4462. Day *.

4474. *In the Syzygies*, the Elevation, from the Actions of both Luminaries, concur, and *the Water is more elevated.*

The Sea aſcends leſs in the Quadratures; for where the Water is elevated by the Action of the Moon, it is depreſſed by the Action
4475. of the Sun, and ſo on the contrary. Therefore, *whilſt the Moon paſſes from the Syzygy to the Quadrature, the daily Elevations are continually diminiſhed:* On the contrary, *they are increaſed, when the Moon moves from the Quadratures to the Syzygy.*

4476. *At a new Moon alſo, cæteris paribus, the Agitations are greater, and thoſe, that follow one another the ſame Day, are more different than at*
* 4467.4471. *a full Moon* *.

4477. *The greateſt and leaſt Elevations are not obſerved, till the ſecond or third Day after the new or full Moon*; becauſe the Motion acquired is not preſently deſtroyed from the Attrition, and other Cauſes, by which acquired Motion the Aſcent of the Water is increaſed. Although the Action by which the Sea is raiſed be diminiſhed; ſomewhat like to what we have demonſtrated elſewhere
* 4006. concerning Heat *.

4478. If now we conſider the Luminaries receding from the Plane of the Æquator, we ſhall perceive that *the Agitation* is diminiſhed, and becomes *leſs*, *according as the Declination of the Luminaries becomes greater*. Which plainly appears, if we conceive them to be in the Poles; for then the Axis of the ſpheroidical Figure coincides with the Axis of the Earth; and all the Sections, that are parallel to the Æquator, are perpendicular to the Axis of the Spheroid, and therefore circular. So that the Water, in every Circle of Latitude, will have every where the ſame Elevation; and ſo in the Motion of the Earth, the Height of the Sea is not changed in particular Places. If the Luminaries recede from the Poles, it is eaſy to find, that the Agitation will be more and more increaſed till it be the greateſt of all, the Spheroid revolving about a Line perpendicular to the Axis, the Axis of the Spheroid being ſuppoſed in the Plane of the Æquator.

Hence

Hence it is plain, why *in the Syzygies, near the Æquinoxes, the Tides are obſerved to be the greateſt*, both Luminaries being in or near the Æquator. 4479.

The Actions of the Moon and Sun are greater, the leſs thoſe Bodies are diſtant from the Earth *; but when the Diſtance of the Sun is leſs, and it is in the South Signs, often both the greateſt æquinoctial Tides are obſerved in the Situation of the Sun; that is, before the vernal, and after the autumnal Æquinox, which yet does not happen every Year; becauſe ſome Variation may ariſe from the Situation of the Moon's Orbit, and the Diſtance of Syzygy from the Æquinox. 4480. * 4302.

In Places diſtant from the Æquator, as the Luminaries recede from the Æquator, the Elevations that happen the ſame Day are unequal. 4481. Plate 127. Fig. 8.

Let P P be the Axis of the Earth, E E the Æquator, L *l* a Circle of Latitude; A B the Axis of the ſpheroidical Figure which the Water forms: When a Place in the Circle L *l* is given at L or *l*, it is given in the ſame Meridian with the Axis of the Spheroid, and the Water is moſt elevated, in both Caſes; yet at L it is more elevated than at *l*; for C L exceeds C *l*, which Lines meaſure the Heights of the Waters, that is the Diſtances from the Center: Theſe Lines would be equal if A L and B *l*, (which are the Diſtances from the Axis of the Spheroid) were equal. But C *l* is leſs, becauſe B *l* exceeds A L, which ariſes from the Inclination of the Axis of the Spheroid to the Æquator.

As long as the Moon is on the ſame Side of the Æquator with any Place, that is, towards the Line C A continued, *the Elevation of the Water is obſerved to be greateſt every Day, after the Moon has paſſed the Meridian of the Place*, for there is the greateſt Elevation when the Place is come to L; but *the Æquator ſeparates, or is between the Moon and the Place*, of which we ſpeak, that is, if the Moon be towards the Line C B continued, the Water again at L will come to the greateſt Height, and, *every Day, the greateſt Elevation of the Sea will be, after the Moon has paſſed through the oppoſite Meridian.* 4482. 4483.

All Things, which have been hitherto explained, would exactly obtain, if the whole Surface of the Earth was covered with Sea; but ſince the Sea is not every where, ſome Changes ariſe from thence not indeed in the open Sea; becauſe the Ocean is extended enough to be ſubject to the Motions we have ſpoken of. But *the Situation of the Shores, the Streights, and many other Things depending upon the particular Situation of the Places, diſturb theſe general Rules.* 4484. 4485.

Rules. Yet it is plain from the moſt general Obſervations, that the Tide follows the Laws which we have explained.

4486. What remains is, to determine the Forces with which the Sun and Moon act upon the Sea, that it may appear, that they are able to produce the Effects which we have mentioned; and that the Actions of thoſe Bodies, upon Pendulums and other Bodies, are inſenſible.

4487. The Increaſe or Addition to the Gravity of the Moon in the Quadratures, from the Action of the Sun, is to the Gravity of the
* 4229. Moon towards the Earth, as 1 to 178, 73 *. In which Computation we have ſuppoſed the mean Diſtance of the Moon, from the
‡ 4217. Center of the Earth, to be 60 Semidiameters of the Earth ‡; therefore the Gravity of the Moon is to the Gravity on the Earth's Sur-
* 4049. face, as 1 to 60 × 60 = 3600 *. Therefore the abovementioned Increaſe is to the Gravity on the Earth's Surface, as 1 to 643428, in which Computation there is an Error to be corrected.

4488. This Computation would be exact, if the Increaſe, of which we ſpeak, was to the Force, with which the Earth deſcends towards the Sun, as the Diſtance of the Moon (which is 60 Semidiameters of
* 4219. the Earth) to the Diſtance of the Earth from the Sun *; but it is as the true mean Diſtance of the Moon, which is $60\frac{1}{2}$ Semidiameters of the Earth, to the Diſtance of the Earth from the Sun. Wherefore the Increaſe, that we have juſt determined, ought to be $\frac{1}{120}$ Part increaſed, and will be to the Force of Gravity on the Earth's Surface, as $\frac{1}{120}$ to 643428, or as 1 to 638110.

4489. This Increaſe of the Gravity of the Moon, in the Quadratures from the Action of the Sun, is to the Increaſe of the Gravity of the Water on the Earth's Surface, in Places which are 90 Deg. diſtant
* 4220. from the Sun, (from the ſame Action of the Sun) as $60\frac{1}{2}$ to 1 *. Therefore this Increaſe of the Gravity is to the Gravity of the Water itſelf as 1 to 38605679. The Diminution of the Gravity,
* 4230. under the Sun, and in the oppoſite Place, is double this Increaſe *;
4490. therefore it is to the Gravity as 1 to 19302839, and *the whole Change in the Gravity, ariſing from the Action of the Sun, is to the Gravity itſelf, as* 1 *to* 12868560.

4491. In order to compare the Action of the Moon with the Action of the Sun, we muſt make Experiments in Places, in which, by reaſon of the Narrowneſs, the Sea is ſenſibly raiſed. Near *Briſtol* at the Autumn and Spring, at which Times the Agitation of the
* 4479. Sea is greateſt *, the Water aſcends in the Syzygies about 45 Feet, more or leſs, in the Quadratures about 25 Feet, more or leſs. Which Numbers are to one another, as 9 to 4. The

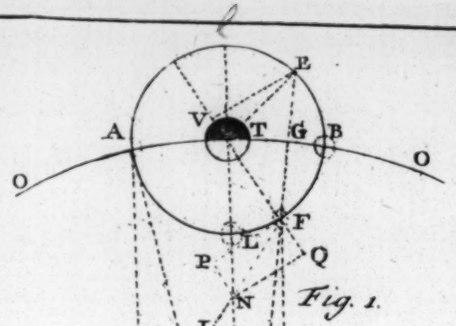


Fig. 1.

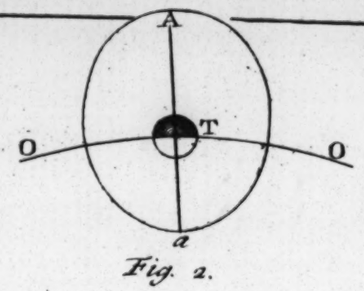


Fig. 2.

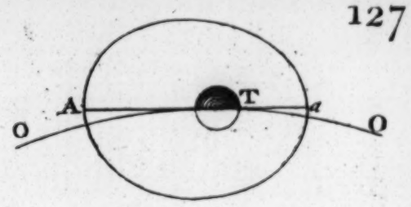
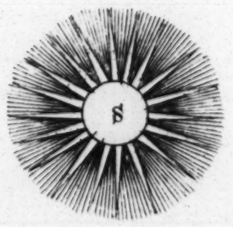
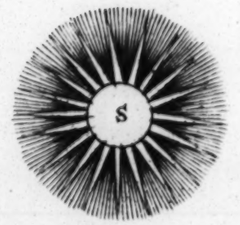


Fig. 3.





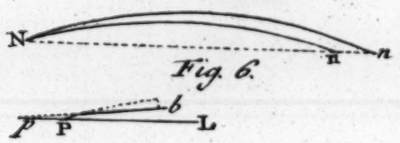


Fig. 6.

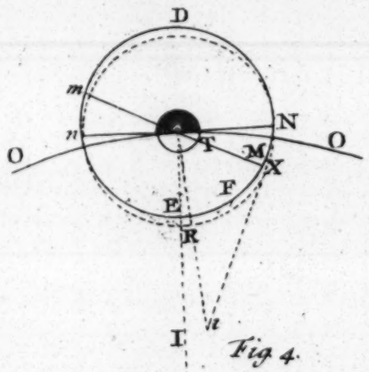


Fig. 4.

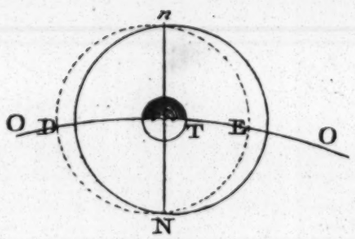


Fig. 5.

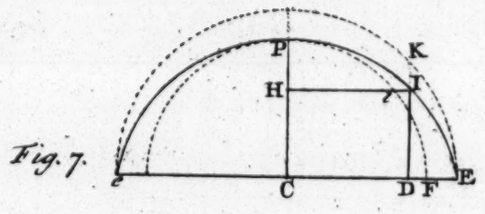


Fig. 7.

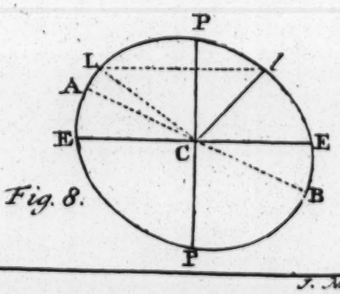


Fig. 8.

J. Alyndo fc.

The Determination of the Forces, which we would find, if the greateſt and leaſt Elevations were exactly at the Time of the Syzygies, would be very eaſy, which we have ſhewn before not to happen ſo *. 4492.

* 4477.

The Diſtance of the Moon from the Syzygy, or the Quadrature, is not always the ſame in the greateſt or leaſt Elevation; for this Diſtance varies, becauſe the Moon is ſometimes more and ſometimes leſs, diſtant from the Meridian, when it goes through the Syzygy or Quadrature. The mean Diſtance of the Moon from the Syzygy, or Quadrature, to which the aforeſaid Obſervations ought to be referred, is about 18 Deg. 30 Min. ſo that the whole Action of the Sun neither conſpires with the Action of the Moon in the Syzygies, nor acts contrary to it in the Quadratures. Alſo in ſuch a Caſe, if at the Syzygy, both the Luminaries be in the Æquator, in the ſaid Diſtance from the Quadrature, the Declination of the Moon is 22 Deg. 13 Min. more or leſs; whereby the Force of the Moon to move the Sea is diminiſhed *. Beſides, *cæteris paribus*, the Diſtance of the Moon from the Earth at the Syzygies is leſs, than at the Quadratures †; whence alſo the Action of the Moon is diminiſhed at the Quadratures *: By attending to all which Things we may diſcover, that *the mean Force of the Sun, to move the Sea, is to the mean Force of the Moon to move the ſame as* 1 *to* 4, 4815. But the Force of the Sun is to the Force of Gravity as 1 to 12868560*; wherefore *the Force of the Moon is to the* ſame *Force of Gravity, as* 1 *to* 2871485. From whence it follows, that theſe Forces of the Moon and Sun are too ſmall, to be ſenſible in Pendulums and other Experiments; but it is eaſily proved, that they are capable of agitating the Sea.

4493.

* 4478.

† 4·54·4256.

* 4480.

4494.

* 4490.

4495.

By diminiſhing the Gravity on the Earth's Surface $\frac{1}{202,5}$ Part, the Sea is raiſed to the Height of 9534 Perches, that is 114408 *Rhynland* Feet *. For each Perch contains 12 Feet; whence by the Rule of Proportion ‡, we find that *the Action of the Sun changes the Height of the Sea near two Feet, and* that *the Action of the Moon changes it* 7,83; *and* that *from the joined Action of both, the mean Agitation is about* 10 *Feet*, which agrees pretty well with Obſervations, for in the open Ocean, as the Sea is more or leſs open, the Water is raiſed to the Height of ſix, nine, twelve, or fifteen Feet; in which Elevations alſo there is a Difference ariſing from the Depth of the Waters, *where the Sea violently enters into Streights or Gulphs; the Force is not broken, till the Water riſes higher.*

4496.

* 4333. 4322.

‡ 4490.

4497.

4498.

4499.

4500.

CHAP. XX.

Of the Moon's Denſity and Figure.

4501. THE Forces of the Sun and Moon, for giving Motion to the Sea, are to one another, in a Ratio compounded of the Ratio of the Quantities of Matter in theſe Bodies * (for all the Particles of Matter act) and the inverſe Ratio of the Cubes of the Diſtances of the Sun and Moon from the Earth †.

* 4048.

† 4457.4471. 4302.

4502. The Quantities of Matter are in a Ratio compounded of the Ratio of the Bulks, that is, of the Cubes of the Diameters *, and the Ratio of the Denſities †; wherefore the Forces abovementioned are directly as the Denſities, and the Cubes of the Diameters, and inverſely as the Cubes of the Diſtances. Here we ſpeak of the mean Denſities, as we have determined them above for different Planets *.

* 18.El.xii.

† 1465. 156.

* 4168.

4503. The apparent Diameters of Bodies, that is, the Angles under which they are ſeen, increaſe as the Diameters themſelves, and diminiſh as the Diſtances; that is they are directly as the Diameters, and inverſely as the Diſtances; therefore the Ratio compounded of

4504. the Ratios of the Cubes of the apparent Diameters *of the Sun and Moon*, and of the Ratio of the Denſities, will be the Ratio of the Forces, whereby thoſe Bodies act upon the Sea. Therefore *the Denſities* of thoſe Bodies *are directly as thoſe Forces, whereby they move the Sea, and inverſely as the Cubes of their apparent Diameters*; and dividing the Forces by the Cubes of thoſe Diameters, you have the Ratio of the Denſities.

4505. The Force of the Sun is to the Force of the Moon, as 1 to 4,

* 4494. 4815 *; the mean apparent Diameter of the Sun is 32 Min. 12 Sec. and the mean apparent Diameter of the Moon is 31 Min. $16\frac{1}{2}$ Sec. that is, they are to one another, as 3864 to 3753. There-

4506. fore *the Denſity of the Sun is to the Moon's Denſity, as* 10000 *to* 48911: which Denſity of the Moon may be compared with the

* 4168. Denſities of *Jupiter*, *Saturn*, and the Earth * and the Moon is denſer than the Earth.

4507. The Quantities of Matter in two Bodies are to one another, in a

* 1465. 156. Ratio compounded of the Denſities and Bulks *; that is, if the Bodies be Spheres, in a Ratio compounded of the Denſities and the Cubes of the Diameters.

The

The Denſities *of the Moon and Earth* are to one another as 48911 to 39539 *; *the* Diameters as 20 to 73†. Therefore *Quantities of Matter*, in thoſe Bodies, *are as* 1 *to* 39, 31. *or as* 0, 0512 *to* 0, 0013. Though the Denſities be diſcovered, if you ſuppoſe the Bodies to be homogeneous; yet the Quantities of Matter will be rightly defined, though the Bodies are not homogeneous; for we determine the Denſity which that Body would have, if the Matter, of which the Body really conſiſts, was equally diffuſed all over it *. 4508. * 4506.4168. † 3751. * 4171.

The Gravities, on the Surfaces of the Earth and Moon, are determined, by multiplying the Denſities by the Diameters *, that is, they are to one another nearly as 3 to 1, or *as* 431 *to* 146, which Number alſo does expreſs the Relation of Gravity on the Surface of the Moon, with the Gravities on the Surfaces of the Sun, *Jupiter* and *Saturn* *. 4509. * 4086. * 4166.

The common Center of Gravity of the Moon and Earth, about which both Bodies are moved, is determined; for it's Diſtance, from the Center of the Earth, *is to the Diſtance* between the Centers of both Bodies, as the Quantity of Matter in the Moon to the Quantity of Matter in both Bodies *; therefore 40, 31 is to 1: as the Diſtance of the Moon, from the Earth, is to the required Diſtance of the Center of Gravity, *from the Center of the Earth*, which is found to be of 2543927 Perches, as is deduced from the known Diameter of the Earth *, and the Diſtance of the Moon. 4510. * 611. 613. * 3750. 4321. 3740.

To determine the Figure of the Moon, we muſt examine what Figure it would have, if it was fluid *. If we conſider the Moon alone at reſt, it would be ſpherical ‡: If we conſider the Action of the Earth upon the Moon, the Moon would acquire the Figure of a Spheroid, whoſe Axis would go through the Earth *. The Force of the Earth, for changing the Figure of the Moon, is to the Force of the Moon upon the Earth, as 39, 31. to 1 †; and as the Diameter of the Moon to the Earth's Diameter ‡, which are to one another as 20 to 73 *, and the Ratio compounded of theſe is 10, 77 to 1. This Force of the Moon is to the Gravity upon the Earth's Surface, as 1 to 2871485 ‡; which Gravity on the Earth's Surface is to the Gravity on the Surface of the Moon, as 431 to 146 *, or as 2871485 to 973166; wherefore *the Action of the Earth, for changing the Moon's Figure, is to the Gravity upon the Moon's Surface*, as 10,77 to 973166, or *as* 1 *to* 90359, the Gravity being changed on the Earth's Surface by $\frac{1}{2871485}$ Part, the 4511. * 4307. ‡ 4308. * 4459. † 4508.4048. ‡ 4457.4302. * 3751. ‡ 4495. * 4509. 4512.

* 4498. the Water is raiſed 8 Feet *; and therefore if Gravity was to be changed $\frac{1}{90359}$ Part, the Elevation would be 254 Feet, as is found by the Rule of Three. If keeping this Diminution of Gravity, we conſider a leſs Body, this Height muſt be diminiſhed, in Proportion to the Diameters: therefore, from the Action of the

4513. Earth, this Elevation of the Moon is of 70 Feet; and *if the Moon be homogeneous, there will not be an Æquilibrium, unleſs the Axis of the Spheroid exceeds the Diameter, which is perpendicular to it*, 140 Feet.

4514. The Elevation of the Moon, from the Action of the Earth, may be diſcovervd by one ſingle Proportion, by knowing the Elevation of the Sea from the Moon's Action; for theſe Elevations are in a duplicate inverſe Ratio of the Gravities on the Surfaces of thoſe Bodies; of which Rule this is the Demonſtration.

4515. If equal Forces acted on thoſe Bodies, they would acquire ſimilar Figures; becauſe the Forces act in the ſame manner upon every Part. The Riſes therefore would be to one another as the Diameter.

4516. Theſe Riſes alſo will be as the Forces themſelves, which are as the Quantities of Matter in the Bodies acting, and as the Diameter

* 4220. of the Bodies, whoſe Figures were changed *. Joining all the Ratios, the Riſes of Water in the Moon and Earth, are in a direct duplicate Ratio of the Diameters of thoſe Bodies, and the inverſe Ratio of the Quantities of Matter in them, that is, in the inverſe Ratio of the Gravity on their Surfaces.

4517. To which Ratio, this very Ratio is to be added to make it duplicate; becauſe the Riſes are alſo inverſely as the Gravities acting on the Particles which are raiſed.

4518. If, ſuppoſing the Moon to be of the Figure which we have now determined, we conceive the Parts to cohere, *the Æquilibrium between the Moon's Parts will not be given, unleſs the* Axis of the Spheroid be directed towards the Earth; whence we ſee why the *Moon always turns the ſame Face towards the Earth*; for by the continual Agitation by which the Axis of the Spheroid is directed towards the Earth, the Moon at laſt has acquired a Motion *about*

* 3743.3899. another *Axis*, of which Motion we have treated before *: which

4519. *Motion is performed in the ſame Time as the Moon turns about the Earth*; which follows from the before-mentioned Action; for if the Celerity was greater, it would be continually retarded by the ſame Force by which the Moon always turns the ſame Face towards the Earth; but it would be accelerated continually, if the Celerity was leſs.

Yet

Yet this Force is great enough, to diſturb ſenſibly at each Revolution the Æquability of the Motion acquired about the Axis: therefore, *the Motion about the Axis is equable, though the Moon be moved in it's Orbit by an unequal Motion* *. The Situation alſo of the Axis of the Moon, cannot be ſo changed by the Force abovementioned, as to be always perpendicular to the Plane of the Orbit, whilſt it's Inclination is changed ‡, therefore the *Axis of the Moon is a little inclined to the Plane of the Orbit*, as we have before ſhewn *. 4520. 4521. * 3739. ‡ 4293. 4522. * 3904.

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ERRATA.

Page 4 Line 3, from the Bottom, for *with* read *to*.
Page 99 and following, for *Reaumur* read *Romer*.